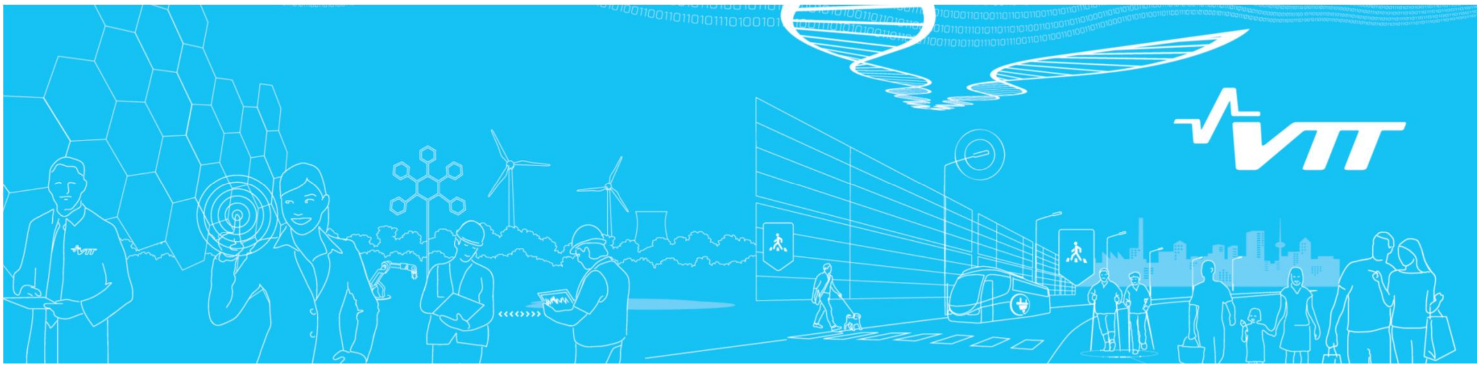

RESEARCH REPORT

VTT-R-01290-14

Case India project

Current biomass supply and utilisation chains for energy in India

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Summary

The project Case India is a part of the Sustainable Bioenergy solutions for tomorrow (BEST) -programme. The project is carried during 2013–2014. In this report it is presented information on the current biomass supply and utilisation technology for energy in India (WP2 Task 2.3 subtask 2 and 3). The study has been made together with VTT and UEF. The study has been carried out by visiting the power plants in India and also gathering information from public domain.

The main remarks from the research are:

- The total installed biomass power and cogeneration capacity in India was 2 664.6 MWe in 2011. It is only about 1.3 % of the total installed electricity capacity (210 952 MW) in India in 2012.
- There are many different kind of agricultural and woody residues available for energy in India. One power plant can use 20–30 different biomass fuels.
- The agro biomass residue potential for energy in India is about 18 000 MWe. The cultivation potential of energy crops on wasteland is 6 200 MWe.
- At the moment the installed direct biomass power capacity in 130 biomass power plants is 990 MWe.
- The alkali metals and chlorine content is high in agricultural fuels causing ash agglomeration and corrosion problems in combustion.
- The biomass fuel price has increased by 30–40 % per year during the few years. At the end of 2013 the price of biomass at the power plant gate was 11.8–35.5 €/ton depending on the biomass fuel and state.
- The biggest share of the biomass fuel price at the gate goes to the farmer. The farmer's share was 84 % in Rajasthan.
- The logistics of transporting, handling and storing the bulky and variable biomass material for delivery to the bioenergy processing plant is a key part of the supply chain that is often overlooked by project developers.
- The main challenges in biomass procurement are: low energy content of biomass fuels, a lot of work is done manually, there is only 2–3 weeks to collect residues from the field before the next crop sowing and small lorries used in transport because of poor road conditions.
- There are different incentives for biomass power plants. One of them is the fixed tariff for biomass electricity.
- The typical sizes of biomass power plants are 7.5–15 MWe. The biomass fuels are local fuels whose energy content is low. For bigger plants, the transport costs can become too high.
- The biomass power plants are based on grate firing technology. The electrical efficiency is low, 20–22 %.
- All together 10 MWe power plant's employment impact is calculated to be about 300 man years.

Confidential	

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Preface

The project Case India is a part of the Sustainable Bioenergy solutions for tomorrow (BEST) -programme. The project is carried during 2013–2014. The project is divided into four tasks: biomass resources (1), biomass supply technology (2) and biomass utilisation for energy (3) and biomass consumption challenges (4).

In this report information of the current biomass supply and utilisation technology for energy in India regarding task two and three is presented. Also in the report data on different biomass fuels and their properties and prices and also some information of the agro biomass and energy crop cultivation potential for energy on wasteland has been presented. The report covers in general the whole India but the presented information is mainly gathered from three selected states of India. These states are Tamil Nadu, Madhya Pradesh and Maharashtra.

The study has been made together with VTT Research Centre of Finland and University of Eastern Finland. The study has been carried out by gathering information from the power plants and from public domain. In the study, the project team has visited several power plants in Tamil Nadu, Madhya Pradesh and Maharashtra during 1.11.2013–31.3.2014. We would like to thank all the power companies in Tamil Nadu, Madhya Pradesh and Maharashtra from the opportunity to visit the biomass plants.

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1. Introduction

Biomass potential use for energy in India

India is the fourth largest consumer of primary energy in the world. Commercial primary energy production in the country for 2009/2010 was around 457.2 Mtoe. Coal, oil and natural gas oil accounted for 97.0 % of the total primary commercial energy production. The share of renewable energy accounts for only 2.5 % and nuclear for 0.5 % of the total commercial primary energy supply (TERI 2014).

The total installed biomass power and cogeneration capacity in India was 2 664.6 MWe in 2011 (EAI catalyzing cleantech in India 2014). It is only about 1.3 % of the total installed electricity capacity (210 952 MW) in India in 2012 (Indian power sector 2014). The total renewable energy (hydro, solar, waste, bagasse and agro biomass energy) installed electricity capacity was 26 368 MW at the end of 2012 (Renew India campaign 2014) being about 11.1 % of the total electricity production capacity.

Biomass as an energy source is an important energy source for India taking into account also the uncommercial energy production. About 32 % of the total primary energy consumption is still derived from biomass and more than 70 % of the country's population depends on it for its energy need (MNRE 2014).

The availability of biomass in India is estimated at about 641.9 mill. tons per year. Based on the studies the estimated biomass surplus is about 243.5 mill. tons per annum corresponding to a potential of about 32 549 MW of electricity. The main biomass potential source is agro biomass, 17 982 MWe. The biomass potential from wasteland is 6 212 MWe and from forest 8 355 MWe. Ministry of New and Renewable Energy (MNRE) has initiated a number of programmes for promotion biomass use for energy. Biomass power generation will generate more than 10 million man days annually in rural areas (MNRE 2014).

Figure 1. 10 MW Biomass Power Project in Maharashtra State in India (MNRE 2014).

Importance of biomass supply in power production

One of the principal challenges facing developers investing in a biomass project is to ensure that a secure and cost-effective supply off biomass fuel is in place. The large share of the cost in biomass energy generation originates from the logistics and storage operations (Bermaco 2014).

The logistics of transporting, handling and storing the bulky and variable biomass material for delivery to the bioenergy processing plant is a key part of the supply chain being often overlooked by project developers. Whether the biomass comes from forest residues on hill country, straw residues from cereal crops grown on arable land, or the non-edible components of small scale, subsistence farming systems, the relative cost of collection will be considerable. Careful development of a system to minimize machinery use, human effort and energy inputs can have a considerable impact on the cost of the biomass as delivered to the processing plant gate (Bioenergy consult 2014).

Biomass supply chains

Biomass feedstock logistics include all of the unit operations necessary to move biomass feedstock from the land to the energy plant and to ensure that the delivered feedstock meets the specifications of the conversion process. The packaged biomass can be transported directly from farm or from stacks next to the farm to the processing plant. Biomass may be minimally processed (i.e. chipped) before being shipped to the plant, as in case of biomass supply from the stacks. Generally the biomass is trucked directly from farm to the power plant if no processing is involved (Bioenergy consult 2014).

Another option is to transfer the biomass to a central location where the material is accumulated and subsequently dispatched to the energy conversion facility. While in depot, the biomass could be pre-processed minimally (i.e. chipped) or extensively (pelletized). The depot also provides an opportunity to interface with rail transport if that is an available option. The choice of any of the options depends on the economics and cultural practices. For example in irrigated areas, there is always space on the farm (corner of the land) where quantities of biomass can be stacked as (Bioenergy consult 2014).

Barriers in biomass supply chain

The biomass supply chain at the moment in India is unsecure. That is why the developers are not so eager to invest for biomass power plants. There are many reasons for the unsecure supply chain:

1. The major problems in use of crop residues as energy source relate to their thin spread over the large area after crop harvest and low bulk density. The low bulk density creates problems in handling, transport and storage. One solution for the low density of agro biomass is upgrading the biomass for instance into pellets or briquettes (Dubey et al. 2010).
2. Biomass agro residues are available only after harvesting period which can stretch for 2–3 months a year. So there is a need to procure and then store the required quantity of biomass within this stipulated time (Bioenergy consult 2014).
3. A lot of straw is burnt at the farm in open fires. It is estimated that about 93 Mt of crop residues are burnt on-farm in the country. The open fires create big health and environment problem.
4. Currently the farmers deliver biomass directly to the power plant. Also there are biomass traders buying biomass from farmers and delivering biomass to power plant. Very many small suppliers create a lot of work for the power plant in paying and receiving the material.
5. In India there is a lot of competition for the biomass. This is the main reason for the increase of the biomass price. Many biomass plants in India have been shut down because of the high biomass price. The main share of the price of biomass goes to the farmer. Studies show that after power plant is commissioned the biomass price starts to increase very rapidly.
6. The road conditions in India are poor. That is why the biomass is transported by small trucks which are not effective and economical.

Figure 2. Straw is burnt in open fires on the field in India.

Target, contents and implementation of the project

The Case India -project is divided into four subtasks: biomass resources (1), biomass supply technology (2) biomass utilisation for energy (3) and biomass utilisation challenges (4). VTT is responsible for the biomass supply (2) and utilisation (3) tasks. In this report it is presented information of the current biomass supply and utilisation technology regarding task two. The target is to analyse the biomass supply and combustion technology in general in the whole country and more precisely in Tamil Nadu, Madhya Pradesh and Maharashtra states (Figure 3). These states are the focus states in the project and located in the south India. In the selected states there is a lot of biomass potential, a lot of industry and a lot of interest for bioenergy. The information of the current technology is gathered by visits to biomass power plants in the target states during 1.11.2013–30.3.2014. Also information has been gathered from public domain. Based on the current supply and combustion technology information the supply chain will be developed to be more effective in case studies in the project.

Figure 3. States of India. The focus states in the project are Tamil Nadu, Maharashtra and Madhya Pradesh.

2. Biomass types and properties

2.1 Biomass fuels in India

There are about 20 major types of agro biomass residues available in India. Currently only paddy husk, mustard crop residues and cotton residues are being widely used. Major sources like paddy straw, wheat straw and wheat pods covering about 40 % of the agro biomass potential in India (16 000-8 000 MW_e) are still left untouched. It is estimated that if only about 50 % of the wasteland available in the country can be put under energy plantation for biomass power an additional 6 200 MW power can be produced (Bioenergy India 2011).

Paddy straw and paddy husk

Paddy straw makes up about half of the yield of paddy (Figure 4). The outermost layer of the paddy grain is the rice husk also called rice hull. The ratio of rice husk/paddy is 0.20 %. It is separated from the brown rice in rice mills.

Figure 4. Paddy straw (left) and paddy husk (right) (Photos by Arvo leinonen).

Maize trash, husk and cob

Maize trash consists of the leaves and stalks of maize plants left in a field after harvest (Figure 5). Maize trash makes up about two and a half times the yield of a maize. Maize husk refers to the leafy outer covering of an ear of maize as it grows on the plant. Corn cob is the core of an ear of maize, to which kernels are attached.

Figure 5. Maize stalks (left) drying in small heaps and maize cobs (right).

Bagasse and sugarcane trash

Bagasse is the fibrous matter that remains after sugarcane are crushed to extract their juice. Cane trash consists of leafy leftovers of the sugarcane harvest (Figure 6). Bagasse is mainly used as a fuel at sugarmills in CHP boilers.

Figure 6. Feeding bagasse at a sugar mill (left) and sugarcane trash on the field In Tamil Nadu (right) (Photos by Arvo Leinonen).

Coconut husk and shell

Coconut fruit has three layers as other fruits - exocarp, mesocarp and endocarp (Figure 7). The exocarp is the thin outermost layer (or skin) of the fruit. The mesocarp is a thick husk composed of coarse brown fibers (coir). The endocarp (shell) is the hard, but relatively thin woody inner layer of a fruit that contains the endosperm. The endosperm is partly solid (fibrous white coconut 'meat', which adheres to the inner wall of the endocarp) and partly liquid (coconut water).

Figure 7. Coconut fibre layer (left) and coconut sells (right) (Photosby Arvo Leinonen).

Coconut frond

Coconut fronds are the stems of coconut tree leaves (Figure 8). Roughly 70 coconut trees can be planted in an acre of land. Each tree gives approximately 12 coconut fronds per year (1 frond per month) weighing each 6-8 kg of wet biomass (60 % MC). In total, 12.4-6.5 tons/acre of coconut fronds are available for biomass supply throughout the year.

Figure 8. Coconut fronds in India at power plant (Photo by Arvo Leinonen).

Cotton stalks

Cotton is a perennial shrub but is it is primarily grown as an annual crop, this helps to prevent the growth of pest population. Cotton is a soft, fluffy staple fiber that grows in a boll around the seeds of cotton plants. Cotton is still a principal raw material for the world's textile industry. In India cotton is mainly harvested by manual plucking. Most of the cotton stalk produced in India (23 mill tons/a) is treated as waste though a small part of it is used as domestic fuel (Figure 9). At the moment main part of the cotton stalks is burnt on the fields after the harvest of cotton crop. The cotton stalks can be harvested and used for energy.

Figure 9. Cottons stalk chops.

Empty palm oil seed punch

The palm seeds are separated from the harvested fresh fruit bunches (FFB) with the help of a large rotating drum. Due to the rotation of the FFB's the palm fruit come loose and fall through the gaps in the drum. The empty palm oil seed punch residues can be used for energy (Figure 10).

Figure 10. Empty palm oil seed bunch (Karthikeyan Natarajan).

Mulberry stalks

Mulberry is a fast growing deciduous woody perennial plant. Mulberry foliage is the only food for the silkworm. In India there are many species of mulberry. The total area of mulberry in the country is around 282 244 ha. The mulberry stalks can be harvested and used for energy use.

Figure 11. Mulberry stalks (Karthikeyan Natarajan).

Soybean stems

Harvesting of soybean can be done by hand, breaking the stems on the ground level with a sickle. The threshing where seeds are separating from the stalks can be done either with the mechanical soybean thresher or some conventional methods used in other legumes. The stems of soybean by-product can be used for energy or animal feeding.

Groundnut shell

India is the second largest producer of groundnuts after China. Gujarat and Tamil Nadu are the main states in groundnut cultivation. The cultivation area of groundnut in India is 8.0 million ha and production 7.5 million tons 2006-2007. Groundnut oil is produced from the groundnut seeds. Groundnut shell residues have great potential for commercial use (Figure 12). It is used as a fuel, filler in cattle fodder, hard particleboard, cork substitute, activated carbon, etc.

Figure 12. Ground shells.

Prosopis juliflora

Prosopis juliflora fuel wood grows vigorously free on dry lands (wasteland) in India. Prosopis juliflora stems are harvested and used for fuel (Figure 13). The yield in harvesting is 50–75 tons/ha (wet). Also Prosopis juliflora is cultivated for energy purposes as an energy crop.

Figure 13. Prosopis juliflora stems on the field (Photo by Arvo Leinonen).

Table 1. Residue to crop ratio of some crops (Dubey et al. 2014).

Crop	**Residue**	**Ratio**
Groundnut	Straw	2.3
Cotton	Stalk	3.5
Jute	Sticks	1.7
Rice	Straw	1.2
Wheat	Straw	1.0
Maize	Stalk and cob	1.2
Sorghum grain	Stalk	0.9

2.2 Seasonal availability of agricultural residues in India

2.2.1 Crop seasons

The crops are harvested in India based on the crop season. There are two main crop seasons and they are kharif and rabi. During kharif season crops are sown at the beginning of the southwest monsoon and harvested at the end of the southwest monsoon. Sowing season is from May to July. *Harvesting season is from September to October.* Important crops are jowar, bajra, rice, maize, cotton, groundnut, jute, hemp, sugarcane, tobacco, etc. (Mohita 2014).

During rabi season crops need relatively cool climate during the period of growth but warm climate during the germination of their seed and maturation. Sowing season is from October to December. *Harvesting season is from February to April.* Important crops for rabi season are wheat, barley, gram, linseed, mustard, masoor, peanuts and potatoes (Mohita 2014).

Besides the kharif and rabi crops, there are certain crops which are being raised throughout the year due to artificial irrigation. *Zaid kharif crops are sown from August to September and harvested from December to January*. Important crops are rice, jowar, rapeseed, cotton, oilseeds. Zaid rabi crops are sown from February to March. Harvesting is made from April to May. Important crops are watermelon, toris, cucumber, leafy and other vegetables (Mohita 2014).

2.2.2 Seasonal availability of biomass

A period of 25–30 days is available after harvesting of kharif and rabi crops for sowing/planting the next crop (Table 2). This period is enough to collect and store the agro residues by cost effective and proper way for biomass delivery later for energy use (Dubey et al. 2010).

Table 2. Seasonal availability of agricultural crop residues in India (Dubey et al. 2010)

Residue	January	February	March	April	May	June	July	August	September	October	November	December
Maize stalk												
Maize cobs												
Cotton stalks												
Mustard husk												
Jute mesta sticks												
Rice husk												
Groundnut shells												
Arhar stalks												

2.3 Biomass properties

A large variety of biomass feedstock is used for energy in India. They are mainly agricultural residues but also woody based fuels like Prosopis juliflora bush, bark and plywood residues are used as a fuel. For effective utilization of biomass fuels, the knowledge of their chemical and combustion properties is essential. The constituents of biomass fuel vary from region to region. Constituents of biomass depend on sources which biomass is collected. The main parameters that have an impact on combustion are moisture, ash, volatile matter, alkali metal, chlorine and sulphur contents and heating value.

Typical problems in combustion are ash agglomeration, fouling and slagging and corrosion (Patel & Gami 2012). The collected data from agro biomass fuels in India is not sufficient for a thorough analysis of the combustion behaviour of the fuels.

The high content of alkalis, potassium and sodium, can cause extensive slag formation and fouling and in fluidised bed boilers, there is also a risk of bed agglomeration. Corrosion problem in biomass fired boiler is largely due to the high chlorine content and low sulphur content in the biomass fuels. Exact analysis of alkali and chlorine content from different biomass fuels are needed before it is possible to analyse precisely the behaviour of Indian biomass fuels in combustion. The alkali and chlorine concentrations can be high compared to Finnish forest residue chips (Table 4).

The moisture content affects the efficiency of the boiler and the combustion process. Moisture content (Table 6) at the gate of agro and woody biomass varies typically from 10 to 50 w-% (occasionally even more). The driest biomass fuels are rice husk and groundnut shell (10 w-%) and the wettest is bagasse (about 50 w-%). The power plants are using several biomass fuels. The different biomass fuels are mixed together before feeding into the boiler. The average moisture content in combustion is 20–30 w-%.

The gross calorific value (GCV) varies at the gate from 12.5 MJ/kg up to 16.7 MJ/kg (Table 6). The average gross calorific value is about 15.3 MJ/kg. The average net calorific value of dry matter is about 14.2 MJ/kg (3.9 MWh/ton). The net average calorific value of wet biomass (30 w-% moisture) is about 8.8 MJ/kg (2.5 MWh/ton).

The ash content rice and wheat straw is high, 16.5-19.2 w-% (Table 3). The ash contents of other biomasses are on the same level as Finnish logging residue chips, 2-4 w-%.

Table 3. Properties of the main crop residues in India (Dubey et al. 2010 & Alakangas 2000).

Biomass fuel	Elemental analysis										Ash
	C %	H %	N %	Na %	K %	P %	Mg %	Ca	O %	S %	%
Arhar stalks	53.3	4.7	0.6	0.05	0.57	0.08	0.40	0.11	-	-	1.98
Bagasse	48.2	6.1	0.2	0.06	0.51	0.04	0.36	0.14	44.4	0.01	3.01
Cotton stalks	51.0	4.9	1.0	0.09	0.61	0.08	0.43	0.12	43.9	0	3.1
Groundnut shell	41.1	4.8	1.6	0.05	1.2	0.12	0.40	0.10	-	-	4.43
Maize cobs	46.2	4.9	0.6	0.03	0.54	0.07	0.28	0.09	-	-	3.02
Maize stalks	41.1	4.2	0.6	0.04	0.42	0.05	0.45	0.08	-	-	2.1
Rice husk	37.8	5.0	0.3	0.02	0.30	0.03	0.17	0.10	35.5	0.03	16.5
Rice straw	36.8	5.0	1.0	0.09	2.5	0.06	0.53	0.08	40.5	0.02	19.2-17.0
Wheat straw	43.8	5.4	1.0	0.06	0.78	0.04	0.35	0.10	-	-	8.47
Coconut shell											2.0
Finnish whole tree chips	51.8	6.1	0.5-2.3		0.15	0.03	0.05	0.28	41.2	0.01	0.5-0.6

Table 4. Selected properties of some biomass fuels in Gujarat state in India (Patel & Gami 2012 & Alakangas 2000).

Biomass	Sulphur %	Nitrogen %	Chloride %	Potassium (K_2O) %	Phosphate (PO_4) %
Cotton stalk	0.17	0.5	1.27	1.67	0.18
Prosopis	0.1	1.02	0.21	0.62	38.21
Bagasse	0.21	0.48	0.56	1.79	0.99
Elephant grass	0.1	0.4	0.77	2.65	25.19
Typha	0.72	0.87	1.61	0.91	0.48
Castor stalk	0.26	0.4	0.28	1.9	0.27
Ipomea	0.46	0.72	0.5	1.49	0.44
Sunhemp	0.4	0.63	0.38	0.89	0.23
Sesbania	0.2	1.15	0.84	1.51	0.32
Finnish whole tree chips	0.01-0.02	0.5-2.3	< 0.01	0.06-0.6	

Table 5. Some combustion properties of few biomass fuels in Gujarat state India (Patel & Gami. 2012)

Biomass	Volatile matter %	Ash %	Fixed carbon %	GCV MJ/kg
Saw dust	72.9	0.6	12.7	16.9
Groundnut shell	68.0	2.8	19.1	16.8
Bamboo leaves	68.7	12.3	11.3	15.7
Cotton stalk	70.3	2.5	19.7	16.7
Prosopis	78.9	0.5	12.9	17.7
Coconut husk	56.7	2.4	27.5	15.9
Jathropa cake	65.1	8.3	19.3	20.0
Rice husk	61.8	16.4	14.6	15.6
Bagasse	77.1	2.4	16.0	19.0
Elephant grass	63.4	5.4	19.7	15.1

Table 6. Gross Calorific values (GCV) and moisture contents of some biomass fuels gathered from one power plant in Tamil Nadu state in India.

Biomass	GCV MJ/kg	Moisture at the gate w-%	Biomass	GVV MJ/kg	Moisture at the gate
Bagasse	16.7	50	**RDF**	14.4	35-40
Casuarina	15.9	20-25	**Paddy husk**	12.5	8-10
Coconut stem	15.5	30-40	**Sugar cane trash**	16.7	8-10
Groundnut shell	16.7	10	**Wheat husk**	14.2	10-15
Prosopis	16.5	30-50	**Wood bark**	14.2	40-45
Match stick waste	15.8	20	**Energy crop**	14.6	45-50

Table 7. Ash compositions of different Indian biomass fuels (Umamaheswaran et al. 2007)

Compound	**Percentage**				
	Groundnut	**Bagasse**	**Arecanut**	**Cashew shell**	**Rice husk**
SiO_2	43.1	65.3	42.5	8.2	93.5
Al_2O_3	10.7	0.5	3.9	3.1	0.0
Fe_2O_3	4.0	0.5	4.2	2.1	0.5
TiO_2	0.6	0.1	0.1	0.1	0.0
P_2O_5	4.2	1.1	7.3	14.7	1.1
CaO	10.8	2.8	1.2	7.5	0.7
MgO	6.1	3.3	0.5	10.7	0.5
Na_2O	5.6	0.1	0.2	5.3	0.4
K_2O	9.6	1.7	18.3	21.7	2.4
Cl	1.4	0.1	3.7	2.0	0.1
MnO			0.0	0.2	
SO_3			5.1	4.1	

3. Biomass potential

3.1 The total biomass potential in India

In the ‘Biomass resource atlas of India’ -report the biomass potential is presented for agro, forest and wasteland biomass in 2002-2004 (CGPL 2014). Agro residues consist of different kind of crop harvesting residues like maize stalks and paddy straw and crop processing residues like mustard and rice husks. Forest biomass consists of different of stalks, branches, leaves, twigs and bark of different logging operations of bushes and trees. Wasteland biomass consists of the same biomass residues like forest biomass collected from wasteland (Figure 14).

In the article ‘EAI catalyzing cleantech in India’ (2014) is presented the agro biomass potential for energy in 2010. The total agro biomass potential (17 982 MWe) is nearly the same as presented by CGPL (2014) for 2002-2004 (18 729 MWe). There are some differences figures between these two sources in biomass state wise potential. In this report the agro biomass potential is presented for 2010 (EAI catalyzing cleantech in India 2014) and wasteland and forest biomass potential is presented for 2002-2004 (CGPL 2014).

From the table below (table 8) it can be seen that the main biomass potential source in India is agro biomass residues, 17 982 MWe (2010). The biomass potential from wasteland (6 212 MWe) and the forest biomass potential (8 355 MWe) is much lower than the agro biomass potential (2002-2004). The total biomass potential in India is about 32 549 MWe.

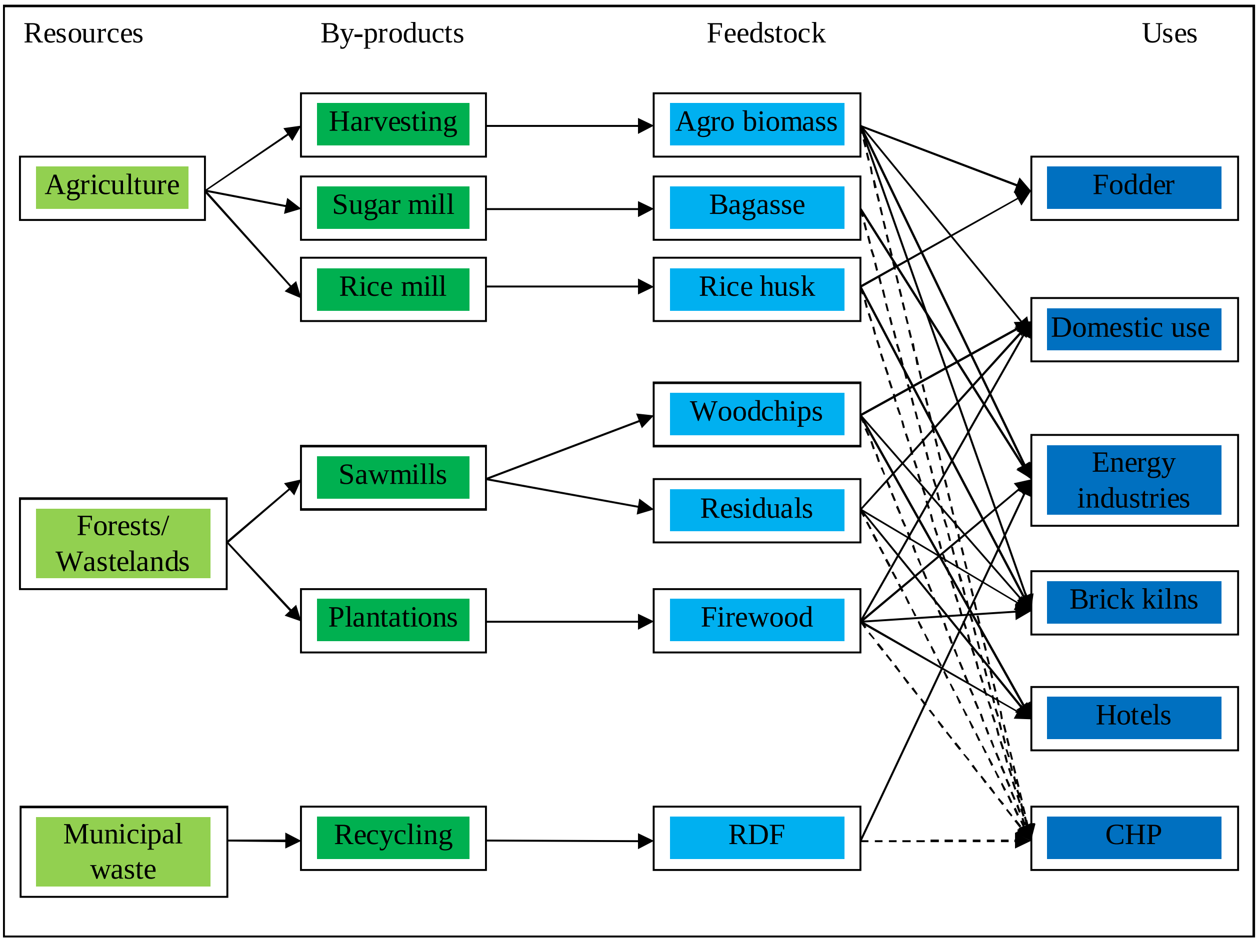

Figure 14. A diagram of different biomass flow to end users.

Table 8. The total biomass and biomass power potential in India. Agro biomass potential is from 2010 (EAI 2014) and wasteland and forest biomass potential is from 2002-2004 (CGPL 2014).

Biomass	**Area (mill. ha)**	**Biomass generation (mill. t/a)**	**Biomass surplus mill. t/a**	**Power potential MWe**
Forest	64.6	89.1	59.7	8 355
Agriculture	105 786.4	546.4	139.4	17 982.0
Wasteland	54.3	66.4	44.4	6 212
Total		**641.9**	**243.5**	**32 549**

3.2 Agro biomass power potential in India

The total agro biomass production in India was about 550 million tons per year in 2010. The surplus of agro biomass has estimated at about 140 million tons per annum in 2010 corresponding to a potential of about 18 000 MWe biomass power (Table 9). From this, about 5 000 MW could be generated through bagasse based cogeneration in the country's 550 sugar mills (MNRE 2014). The rest about 13 000 MW comprises direct biomass power. In the whole India the main agro residues are paddy straw and husk, cotton stalks, husk and pods, wheat stalks and pods, maize stalks, banana residues and coconut fronds in India. The crop residue types differ from state to state (Table 10). Paddy straw has the biggest potential in India (Figure 15). More information of the crop residue potential in different states is presented in appendix 1.

Rajasthan, Punjab, Maharashtra, Haryana and Gujarat are the states having high agro biomass potential. These states are located in the north India. Together, they comprise about 60 % of the total estimated potential (17 982.0 MWe) for agro biomass in India (Table 9). The agro biomass potential in the focus states in Case India -project is also high. In Maharashtra it is 1 585 MWe, in Tamil Nadu 863 MWe and in Andra Pradesh 150 MWe (Table 9).

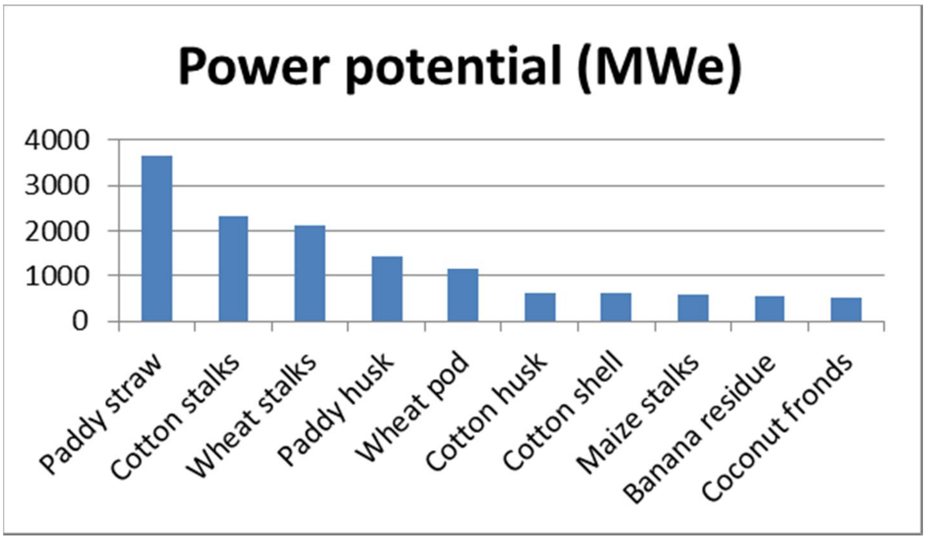

Figure 15. The power potentials of the main agro residues in India (Sonde 2011).

Table 9. The agro biomass power potential in 2010 and installed biomass and cogeneration power capacity in key Indian states in 2011 (EAI catalyzing cleantech in India 2014 and MNRE 2014).

State	Crop area ha	Crop production mill. ton/a	Biomass production mill. ton/a	biomass surplus mill ton/a	Power potential 2010 MWe	Installed capacity 2011 MWe
Andra Pradesh	2 540.2	3.2	8.3	1.2	150.2	363.3
Chattisgarh	3 815.5	6.1	10.1	1.9	220.9	231.9
Gujarat	6512.9	20.6	24.2	7.5	1 014.1	0.5
Haryana	4 890.2	13.5	26.2	9.8	1 261.0	35.8
Karnataka	7 277.3	38.6	23.8	6.4	843.4	365.2
Kerala	2 041.7	9.8	9.4	5.7	762.3	0
Madhya Pradesh	9 937.0	14.2	26.5	8.0	1065.4	1.0
Maharashtra	15 278.0	51.3	36.8	11.8	1 585.0	403.0
Punjab	6 693.5	27.8	46.3	21.3	2 674.6	74.5
Rajasthan	12 537.5	93.7	204.9	35.5	4 595.0	73.3
Tamil Nadu	2 454.0	24.5	16.0	6.7	863.70	488.2
Uttar Pradesh	12 628.2	46.8	50.4	11.7	1 477.9	592.5
Others	19 180.1	49.3	63.5	11.9	1 468.5	35.4
All together	105 786.4	399.3	546.4	139.4	17 982.0	2664.6

There are more than 20 different kind of agro biomass available for fuel in India. In *Tamil Nadu* state the main agro biomass residues are paddy straw and paddy husk, maize stalk and husk, groundnut stalk and shell and cotton stalk (Table 10). In *Andra Pradesh* the main agro residues are paddy husk and straw, maize stalks and cobs, groundnut stalks and shells, jowar stalks and pods and cotton stalks and husk. In *Maharashtra* state the main agro residues are groundnut stalks and shells, soybean stalks and cotton stalks and husk (Sonde 2011).

Table 10. The main agro biomass residues in different states in India (Sonde 2011).

State	Paddy husk	Paddy straw	Wheat straw	Wheat pod	Maize stalks	Miaze cobs	Mustard husk	Castor seed	Groundnut stalk	Groundnut shell	Bajra stalks	Bajra cobs	Soybean stalks	Arhar stalks	Jowar stalks	Jowar pods	Tapioca stalks	Cotton stalks and husk	Tea sticks	Arecanut fronds and husk
Andra Pradesh	X	X			X	X			X	X					X	X		X		
Arunachal Pradesh	X	X			X	X	X												X	X
Assam	X	X					X													
Bihar	X	X	X	X	X	X														
Chattisgarh	X	X																		
Goa	X	X																		
Gujarat			X	X	X	X		X	X	X	X							X		
Haryana	X	X	X	X			X				X	X						X		
Himachal Pradesh	X	X	X	X	X	X														
Jammu & Kashmir			X	X	X	X														
Jharkhand	X	X																		
Karnataka	X	X			X	X			X	X					X	X		X		
Kerala	X	X															X			X
Madhya Pradesh	X	X	X	X	X	X	X						X	X	X	X		X		
Maharashtra									X	X			X					X		
Manipur	X	X			X	X														
Meghalaya	X	X													X	X				
Mizoram			X	X																
Nagaland	X	X																		
Orissa	X	X			X	X			X	X										
Punjab	X	X	X	X	X	X	X											X		
Rajasthan			X	X	X	X	X				X	X						X		
Sikkim					X	X														
Tamil Nadu	X	X			X	X			X	X	X						X	X		
Tripura																				
Uttar Pradesh	X	X	X	X	X	X					X	X								
Uttarakhand	X	X	X	X																
West Bengal	X	X	X	X															X	

3.3 Biomass potential on wasteland

The total wasteland area in India is 54.3 million ha. Maharashtra, Gujarat and Madhya Pradesh states have the largest wasteland area (Table 11). These states are located in the Western India. Biomass potential on wasteland consists of different of stalks, branches, leaves, twigs and bark of different logging operations of bushes and trees. The total biomass potential on wasteland is 66.4 mill. tons per annum and the current biomass power production potential on wasteland is 6 200 MW_e (CGPL 2014).

Table 11. Biomass power potential from wasteland in the main states of India in 2002–2004 (CGPL 2014).

State	Area (kha)	Biomass generation kT/a	Biomass surplus kT/a	Power potential MWe
Maharashtra	7 439	10 826	7 317	1 024
Gujarat	7 729	10 676	7 192	1 005
Madhya Pradesh	7 329	10 340	6 897	967
Jammu & Kashmir	6 894	8 158	5 384	754
Rajasthan	10 975	6 703	4 424	619
Andra Pradesh	2 799	4 138	2 799	392
Chattisgarh	1 693	2 388	1 592	223
Uttar Pradesh	1 556	2 223	1 490	209
Karnataka	1 504	2 161	1 426	200
Jharkhand	1 083	1 571	1 047	147
Arunachal Pradesh	923	1 151	838	117
Himachal Pradesh	901	1 190	786	110
Tamil Nadu	693	1 145	756	106
Others	2737	4829	2434	341
All together	**54 253**	**66 355**	**44 369**	**6 212**

3.4 Cultivation of energy crops on wasteland

The biomass potential from wasteland can be increased by cultivating energy crops on wasteland. There are many energy crops that are able to grow on wastelands in India. They are Eucalyptus, Bamboo, Jathropa, Casuarina and Prosopis juliflora. Eucalyptus and Bamboo are mainly used for pulp and paper production. The expectations for the use of Jathropa in bio-oil production have been very high in India. The experiences from Jathropa cultivation have not been so good. That is why the main fast growing energy crop species in India are Casuarina and Prosopis.

There are many challenges on biomass fuels production on wasteland using energy plantations (MSS research 2001):

- low soil fertility,

- little or no irrigation potential,

- not suitable for crops that require fertile soil and continuous water supply,

- high cost investment in soil irrigation development,

- improved technology required to make lands productive and

- complex organization required for land development, cultivation, production and marketing.

Cultivation of fast-growing trees can serve as biomass fuel for establishing a national network of decentralized rural power plants. These power plants (10–25 MW in size) can generate thousands of megawatts of power (MSS research 2001).

3.4.1 Bamboo

Bamboo is a perennial giant grass, but Bamboo is often called a tree (Figure 16). The bamboo trees grow in wild in most parts of India, particularly in the hilly woods of western and southern India. It is also cultivated only in the lower Himanlayas and in the valleys of the River Ganga and Indus. There are 136 species of bamboos in India. The bamboo forest area in India is 11.4 mill. ha in 2005, which constitutes about 13.0 % of the total forest area. Large bamboo areas are reserved. The annual harvest of Bamboo in India is about 13.5 million tons. 35 % of harvested bamboo is used for pulp production. The average annual yield from the Bamboo forest is only in average 2.0 tons/ha. The total bamboo growing stock was 80.4 million tons in 1995 (Bamboo house India 2014).

At the moment there is an interest to grow bamboo as energy crop. Bamboo is drought resistant and has a wide range of soil/climatic adaptability and it grows on marginal and degraded land from coastal regions to mountain slopes under moist or semi-arid conditions (Mehra and Mehra 2007).

The harvest of bamboo starts after 24 months. By then the bamboo would have grown to a size of 7.5 cm in the bottom with a height of 4.6-6.1 m. Each plant can weigh 6 to 10 kg (dry). Under ideal condition, the first year yield can be about 75 tons of dry biomass per ha. The annual yield depends on the environment as well as the species. It is generally 5-12 tons/ ha from plantations. Well-managed commercial bamboo planation matures within 4 - 5 years (Mehra and Mehra 2007, Sustainabilitynext 2013 and Keralaagriculture 2014.). At the moment in Tamil Nadu there is a power company is planning to grow bamboo as contract farming basis (Sustainabilitynext 2013).

The total establishment investment and maintenance costs for one ha bamboo plantation are 279 € (23 600 Rs) for 6 years without land costs. The establishment and maintenance costs are 0.62 € (53.1 Rs) per ton assuming the yield per ha is 74.1 tons/ha/a (Mehra & Mehra 2007).

Figure 16. Bamboo trees.

3.4.2 Eucalyptus

Eucalyptus (Figure 17) has a long history in India. It was first planted around 1790 near Bangalore. The most important species is Eucalyptus hybrid and Eucalyptus tereticornis. The reasons for the popularity of Eucalyptus hybrid in India is the suitability for Indian conditions and because it is fast growing, coppices well, fire hardy and it has a good ability to adapt to a wide range of edapho-climatic conditions. Up to now over 1 000 000 ha of eucalyptus plantations have been established. The plantations have been established mainly between 1960–1980 decades. The largest eucalyptus plantation area is located in Gujarat (50 000 ha), Haryana (25 000 ha), Kerala (38 000 ha, Madhya Pradesh (45 000 ha), Maharashtra (150 000 ha), Tamil Nadu (80 000 ha), Uttar Pradesh (100 000 ha), West Bengal (200 000 ha) and Karnataka states (more than 130 000 ha) (Palanna 2014).

The yield of Eucalyptus plantations varies considerable depending on the site and the edepho-climatic conditions. The average yield is 2.5 tons/ha/a. The average yield in the private plantation is much higher (5 tons/ha/a) (Regional office for Asia and the Pacific 2014). Eucalyptus is harvested in 8–9 years for pulpwood production. When harvesting Eucalyptus for timber, the age is 13–14 years.

Eucalyptus is mainly used for pulpwood. The farm forestry sector harvests and sells 150 000 tons of pulpwood. Eucalyptus is also used as a fuel in households, for charcoal production and poles and timber production (Palanna 2014). Also Eucalyptus can be used as a short rotation energy crop.

Large scale planting of Eucalyptus has caused a concern about the high water use and nutrient depletion in Eucalyptus plantations India. A number of studies have been undertaken in various sites on water use of Eucalyptus but none of the findings are conclusive. The nutrient depletion in Eucalyptus plantations has been studied also. According to the study the organic and potassium are depleted in the soil under Eucalyptus more than in wood lands, but no difference in calcium and magnesium was observed (Palanna 2014).

Because of the controversy of eucalyptus plantation suitability for Indian conditions, the soil and climatic conditions must be assessed more precisely before the Eucalyptus plantations are established.

Figure 17. Eucalyptus plantation in India (Palanna 2014).

3.4.3 Casuarina equistifolia as an energy crop

Casuarina equistifolia (Figure 18) is a fast growing tree that can be cultivated on marginal waste land and harvested on a rotating basis from the third to fourth year. This species grows well in very sandy soils along the coast, soils which are often non-productive for food crops. Casuarina is already commercially cultivated over wide sites in the southern states, primarily as a rain-fed crop for fuel and construction. It can also be used as pulp for papermaking. It has been found an excellent species for environmental control of erosion, stabilization of soils and reclamation of poor soils. Casuarina equistifolia has a calorific value of about 14.6 MJ/kg (3 500 kcal/kg) and contains less water than most wood species (MSS research 2011).

The results of the economic calculation of Casuarina equistifolia (Table 12) as an energy crop (MSS research 2011) are:

- One hectare of Casuarina under rain-fed conditions can produce on average 200 tons of fuel in four to five years, an average of 40 to 50 tons per annum.
- It requires 10 000 tons of Casuarina to generate one megawatt electricity for a year.
- By harvesting the crop on a rotating basis, a standing plantation of 250 hectares is sufficient to generate one megawatt of electric power. A 2 500 hectare Casuarina energy plantation can support a 10–12 MWe power plant.
- Assuming a net farm selling price of 8.3 € (700 Rs) per ton, one hectare of Casuarina can generate year-round net income of 331 € (28 000 Rs).
- Allocating one hectare per person, each 10 MW power plant can provide employment for 2500 persons.

A portion of the wasteland needed for energy plantation can be leased out to private parties and cultivated by landless families using advanced practices with fast growing tree crops. Corporate control of a portion of the land will ensure availability of raw material which is essential to attract private investment in the power plants. Local landless labor will be employed by the corporates for cultivation and harvesting. An equal area can be leased directly to landless families to cultivate the same crops and register their crop with the power plant to obtain bank finance to meet the cost of cultivation (MSS research 2001).

Figure 18. Casuarina junghuhniana plantation in India (Sankar 2010).

3.4.4 Prosopis juliflora as an energy crop

Prosopis juliflora is a fast growing tree and it is well adapted to warm and dry tropical climates (Figure 20). It grows well in areas receiving 250–600 mm annual rainfall. It grows rapidly, producing 10–28 tons of biomass on dry-weight basis per hectare per annum. The wood is hard and gross calorific value is about 16.7 MJ (4 000 kcal/kg). It grows well in sandy, loamy, sodic, saline, alkaline and marshy soils with very little input and at very low cost. The biomass is an excellent raw material for power generation. 1 000 hectares Prosopis juliflora can provide sufficient amount of fuel to generate one MW of electric power (MSS research 2001 and CAZRI 2014).

Prosopis juliflora already grows wild on extensive areas of wasteland. It is now found in many states of India: Andra Pradesh, Karnataka, Maharashtra, Orissa, Punjab, Uttar Pradesh, Tamil Nadu and West Bengal. At the moment Prosopis juliflora is not used only for fuel but also for fodder, charcoal and timber production (CAZRI 2014)

The results of economic calculation of Prosopis juliflora cultivation (Table 12) for energy purposes (MSS research 2001) are:

- One hectare of Prosopis juliflora can produce in rainy conditions on average 10 tons of fuel per hectare per year, from the 3rd year onwards.
- By harvesting the crop on a rotating basis, a standing plantation of 1 000 hectares is sufficient to generate one megawatt of power year round. A 10 000 ha Prosopis juliflora energy plantation can support a 10 MWe power plant.
- Assuming a net farm selling price of 8.3 € (700 Rs) per ton, one hectare of Prosopis can generate year-round net income of 82.8 € (7 000 Rs). (In the calculation one € is 84.5 Rs).
- Each hectare requires 100 man-days per annum of labour impact.
- Allocating two hectares per person, a 10 MW power plant can provide employment for 5 000 persons, each earning 166 € (14 000 Rs) per annum.

The economic feasibility of energy crop cultivation has been studied also in four case studies in Haryana state in India (Figure 19) (Stille 2011). In Gudha case study the energy crops were Acacia nilotica (50 %) and Eucalyptus tereticornis (50 %), in Kohand case study the energy crop were Acacia nilotica, in Nain and Sutabna case studies the energy crop was Prosopis juliflora. The production of energy crops in the case studies were calculated and compared to the market price of fuelwood, timber and charcoal. The production of fuelwood and charcoal in Gudha and Kohand case studies is economical because of the low feedstock costs. In Nain and Sutana case studies the Prosopis juliflora cultivation was not so attractive because of high feedstock costs (Stille 2011).

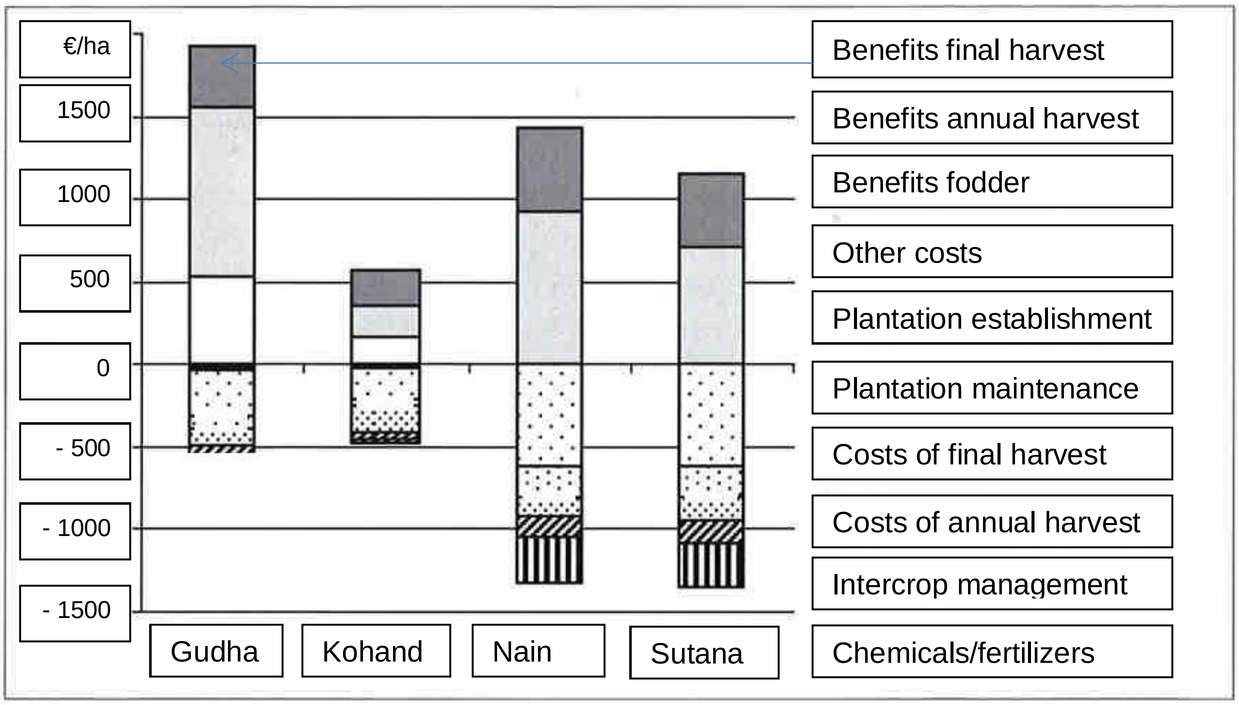

Figure 19. Cost/benefit breakdown of the four case study plantations (Stille 2011).

Table 12. Economics of energy crops cultivation for energy (MSS research 2001). One € is 84.5 Rs.

	Casuarina	**Prosopis**
Initial cost of after 1st year(without labour) €/ha (Rs/ha)	23.7 (2 000)	5.9 (500)
Rotation period, a	5	3
Capital cost until harvesting begins, €/ha (Rs/ha)	71 (6 000)	5.9 (500)
Average yield per hectare per year, ton/ha (dry)	40	10
Price per ton (net at farm), €/ton (Rs/ton)	8.3 (700)	8.3 (700)
Average annual gross income, €/ha (Rs/ha)	331 (28 000)	82.8 (7 000)
Average annual net income. €/ha (Rs/ha)	320 (27 000)	82.8 (7 000)
Plantation for 10 MWe power, €/ha (Rs/ha)	2 500	10 000
Employment generation per plantation, person	2 500	5 000
Average annual income per person, € (Rs)	320 (27 000)	165.7 (14 000)

Figure 20. Prosopis juliflora growing wild in Tamil Nadu (Photo by Arvo Leinonen).

3.5 Power potential from forest biomass

The total forest area in India 64.5 million ha. Chattisgarh, Orissa, Madhya Pradesh and Arunachal Pradesh states have the largest forest area (Table 13). These states are located in the Eastern India. Biomass potential from forest consists of different of stalks, branches, leaves, twigs and bark of different logging operations of bushes and trees. The total biomass potential of forest biomass is 59.7 mill. tons per annum and the current biomass power production potential on forest biomass is 8 355 MW_e (CGPL 2014).

Table 13. Biomass power potential from wasteland in the main sates of India in 2002–2004 (CGPL 2014).

State	**Area (kha)**	**Biomass generation kton/a**	**Biomass surplus kton/a**	**Power potential MWe**
Chattisgarh	7 069.6	11 204.5	7473.1	1 046.2
Orissa	6 210.6	9 282.4	6 027.8	843.9
Madhya Pradesh	5 473.2	8 058.2	5374.7	752.5
Arunachal Pradesh	4 544.9	7 161.8	5 207.6	729.1
Karnataka	5490.3	7 840.0	5 174.4	724.4
Maharashtra	5 738.8	7 580.9	5 123.5	717.3
Uttaranchal	2 873.4	4 542.8	3 044.3	426.2
Tamil Nadu	2 494.3	3 506.9	2 314.6	324
Jharkhand	2 424.1	3 305.2	2 202.6	308.4
Uttar Pradesh	2 301.0	3 255.8	2 181.8	305.5
Others	19 950.1	23 380.6	17 553.6	2 177.4
All together	**64 570.3**	**89 119.1**	**59 678.0**	**8 354.9**

4. Biomass use for energy

4.1 Installed biomass power capacity in India

The total installed biomass power and cogeneration capacity in India was 2 664.6 MWe in 2011. From the total installed biomass power the share of direct biomass power is 990 MW, the share of cogeneration of bagasse is 1 649 MWe and the share of gasification power 125 MWe (EAI catalyzing cleantech in India 2014). The installed direct biomass power capacity (990 MW_e) is 37.1 % from the total installed biomass power capacity (Pothan 2012).

The highest biomass power capacities were installed in Andra Pradesh (363 MWe), Tamil Nadu (488 MWe), Maharasthra (403 MWe), Karnataka (365 MWe) and Uttar Pradesh states (593 MWe) in 2011. The share of the installed power capacity of these states from the total biomass power capacity in India was 83 % (Pothan 2012 and Paliwal 2012).

The number of biomass power plants was 118 in India 2012. The size of the direct biomass power plants is 8–15 MWe (Paliwal 012). They are suitable for Indian conditions. One reason for that is that the transport distance must be under 50 km because the energy content of agro biomass is low (Bioenergy consult 2013). If the transport distance is higher the biomass must be upgraded for instance by pelletizing.

Currently 72 from the commissioned biomass power plants have been closed. In Chattisgarh state 25 power plants from 29 power plants have been closed. The main reason for the high number of closed power plants in India is the increased biomass fuel price. Also the government has not updated the tariff of biomass power annually because of the increased biomass fuel price (Paliwal 2012) (Table 14).

Table 14. Number of commissioned and closed biomass plants in India in 2012 (Paliwal 2012).

State	Number of commissioned biomass power plants	Number of closed power plants
Andra Pradesh	39	22
Chattisgarh	29	25
Tamil Nadu	23	12
Maharashtra	17	11
Rajasthan	10	2
All together	118	72

4.2 Industrial CHP in India

The industrial sectors where CHP (or co-generation) has been applied in India include e.g. sugar, chemical, fertilizer, pulp&paper, cement and textile industries. There are no up-to-date estimations of the current total CHP capacity India but in 2008 IEA estimated that total capacity in 2005 was 10 GWe (IEA 2008), which would be some 5 % of the total current electricity capacity.

Also, studies or estimates of the current CHP installed capacities in different industrial sectors and types and amounts of fuels used are lacking in other sectors than sugar industry. According to IEA (IEA 2014) CHP in industry in India has been primarily based on internally produced fuel, industrial residue or waste (such as bagasse in the sugar industry) and on conventional fuels such as coal.

Even though fuel specific data of industrial CHP is currently unavailable, some idea of fuels used (or that could be used) in CHP can be obtained from the overall industrial energy demand break-down shown in Figure 21. It shows that almost 2/3 of the demand is met by coal and oil, and 18 % comes from biomass and waste.

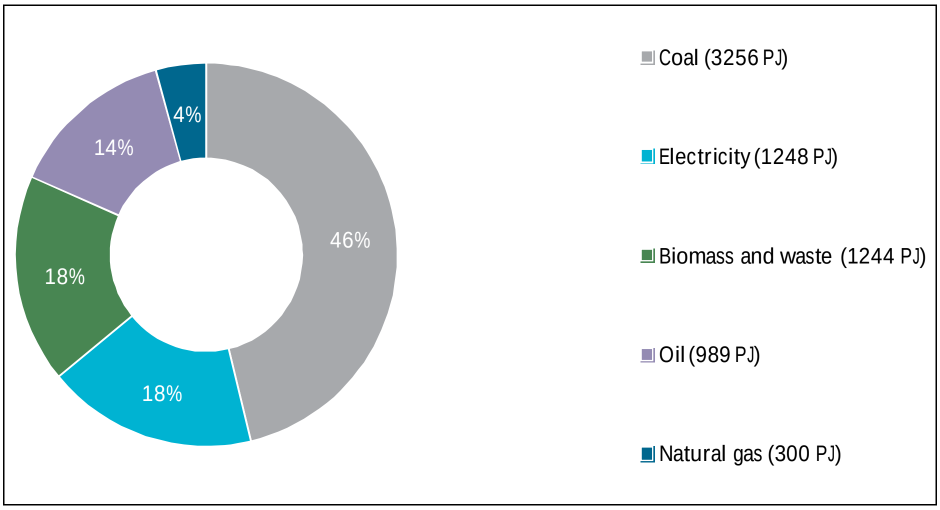

Figure 21. Industrial energy demand by fuel in India, 2011 (IEA 2013).

In India, CHP is most established in the sugar industry. In 2010–2011 India was the second largest producer of sugarcane in the world. In its 527 sugar mills 240 Mt of cane gets crushed per year generating around 80 Mt of wet bagasse of which 70 Mt is used for meeting the captive heat and power demands. (Press Information Bureau, Government of India, 2012.)

To produce steam and electricity from bagasse, all sugar mills in India have co-generation plants for captive use. Ministry of New and Renewable Energy (MNRE) provides fiscal and financial incentives for selling the surplus electricity generated at the sugar mills. As on the end of March 2013, 213 sugar mills with a total installed capacity of about 2.3 GW where under the scheme on biomass power/ bagasse co-generation to generate and sell the excess electricity (Table 15). The Government of India has set a target to further increase the capacity to 3.4 GW by the end of 2017 (Government of India 2013).

Table 15. State-wise list of commissioned bagasse co-generation plants selling excess electricity as on the end of March 2013 (Press Information Bureau and Government of India 2013).

State	**No. of Plants**	**Bagasse Co-generation (MW)**
Andhra Pradesh	22	163.05
Bihar	4	43.30
Haryana	4	31.80
Karnataka	32	403.88
Maharashtra	65	580.90
Punjab	6	62.00
Tamil Nadu	26	327.00
Uttar Pradesh	53	710.50
Uttarakhand	1	10.00
Total	**213**	**2332.43**

For other biomass based CHP, not much data is available but for example for non-bagasse biomass based captive CHP, the Government of India reported a cumulative additional capacity of 373 MW in the period 2005–2012 (Figure 22).

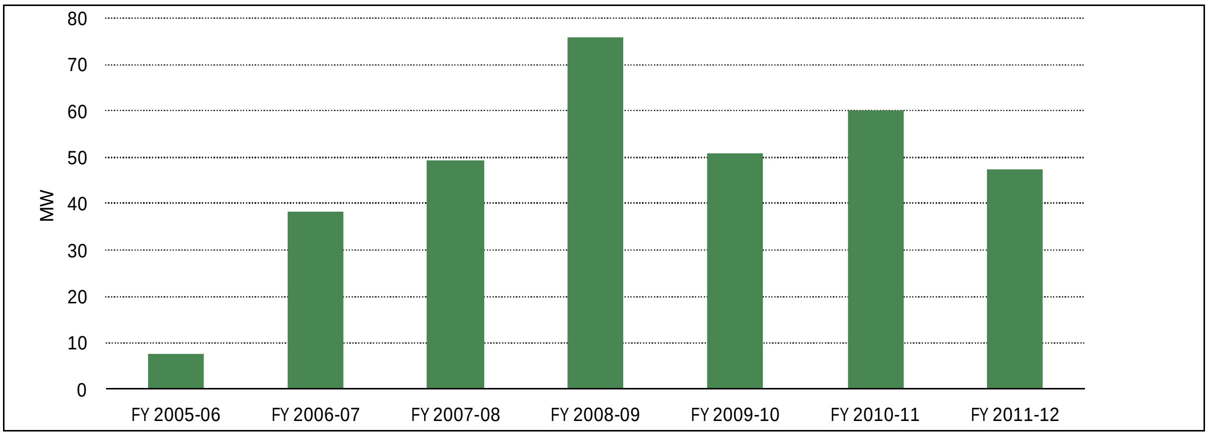

Figure 22. Captive CHP capacity based on non-bagasse biomass in India, 2005 to 2012. (Figure from IEA 2014).

According to Singh et al. 2013, the total industrial CHP potential in India is 14.6–15.6 GW. Sugar industry (5.2 GW) and distilleries (2.9 GW) represent the largest individual sectors (Figure 23) – both of which are also benefiting from incentives from the central government. Many industries in India have potential to deploy CHP technologies, but no other industry receives the level of government support that the sugar and distillery industries do. In some industries, CHP projects are often implemented to ensure a reliable power supply rather than for economic and environmental benefits. (IEA 2014)

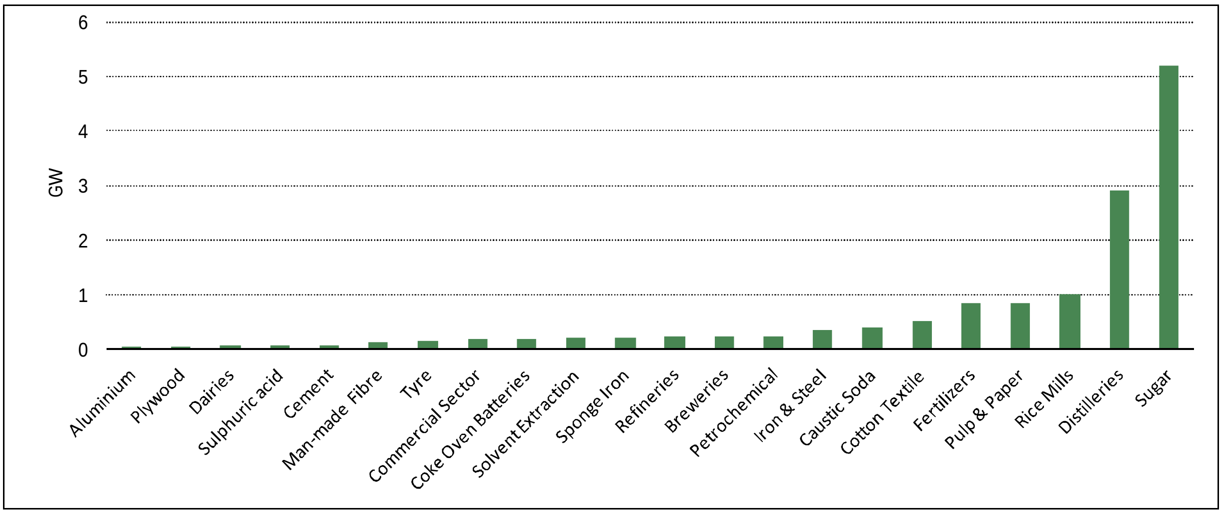

Figure 23. Potential for industrial CHP deployment in India (Figure from IEA 2014, data originally from Singh et al. 2013).

5. Biomass incentives and price in India

5.1 Biomass subsidies in India

There are various financing/subsidy mechanisms for biomass power projects in India. Indian Renewable Energy Development Agency (IREDA) provides *soft loans* for setting up biomass power. *Capital subsidies* are also available for biomass power projects. In addition, State Electricity Regulatory Commission (SERC) has determined preferential *fixed tariffs* for biomass and cogeneration electricity (Table 16) and Renewable Purchase Standards (RPS). Also there are available *concessional custom duty and excise duty exemption* on equipment required for initial setting up biomass projects based on certification by Ministry (Bioenergy 2011). Also there are *other fiscal incentives*. In 2012 the fiscal and financial incentives have proposed to continue under the Twelfth Five Year Plan period (EnergyNext 2014). Also there are used *Clean Development mechanism (CDM) and Renewable Energy Certificate (REC) mechanism benefits* for bioenergy projects in India.

The capital subsidy in the northern part of India is 29 586 € x MWe ^ 0.646 (2.5 million Rs x MWe ^ 0.646) and in other states it is a little bit lower 23 669 € x MWe^0.646. The northern part of India includes northeast region and Sikkim, Jammu and Kashmir, Himachal Pradesh and Uttaranchal states (Bioenergy 2011). One MWe power plant investment costs are near 0.98 million € (83 million Rs) (Paliwal 2012). So the capital subsidy per one MW power plant is 18 462 € (1.56 million Rs) and it is about 2 % from the investment costs per MWe.

Clean Development Mechanism (CDM) is an international mechanism introduced by the Kyoto Protocol. The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in how they meet their emissions reduction or limitation targets. CDM allows an industrialized country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) or carbon credits, each equivalent tonne of CO_2, which can be counted towards meeting Kyoto targets (United Nations 2014). CDM mechanism has been an important contributor in India in biomass sector. In 2011 there were 166 biomass projects that were utilizing CDM mechanism. One of the power plant that was utilizing CDM mechanism is the Orient Green Power Ltd. biomass plant in Kariyanchettipalayam village in Tamil Nadu (UN 2014). Value of carbon credit was 17.8 €/MWh (1 500 Rs/ MWh) in Tamil Nadu in November in 2013. The value of carbon price is 21.1 € per ton of CO_2 (1 786 Rs per ton of CO_2). In January 2014 the European carbon credit price was about 5 €/ton of CO_2.

Renewable energy certificate (REC) -mechanism is national mechanism to encourage renewable energy generation in India. It is similar to CDM mechanism. Central Electricity Regulatory Commission (CERC) introduced REC mechanism to ease the purchase of renewable energy by the state utilities and obligated entities, including the states which are not well endowed with RE sources. REC framework seeks to create a national level market for renewable generators to recover their cost. One REC (Renewable Energy Certificate) represents 1 MWh of energy generated from renewable sources. Under the REC mechanism, a generator can generate electricity through the renewable resources in any part of the country (Indian energy index2014). To be eligible for REC mechanism, the purchase power agreement (APP) must be signed at the average purchased pooled cost (APPC) not at the preferential tariff. REC price is fixed and it is 17.8 €-46.2 € (1 500–3 900 Rs) for non-solar projects. The APPC changes from state to state in India. In Andra Pradesh it was in 2011 21.9 €/MWh (1 850 Rs/MWh), in Maharashtra 28.8 €/MWh (2 430Rs/MWh), in Karnataka 21.9 €/MWh (1 850 Rs/MWh) and in Tamil Nadu 31.0 €/MWh (2 620 Rs/MWh) (Agneya carbon ventures 2011).

REC and CDM mechanisms are independent of each other. In certain conditions the electricity generator can be eligible for REC and CDM benefits.

Also in India there is created *Feed-in Tariff (FIT) system* for renewables. It is 'A renewable energy policy that offers a guarantee of payment to renewable energy developers for the electricity they produce'. The biomass power tariff is different in the different states in India (Table 16). Most of the biomass plants in India have been set up with the State Electricity Board (SEB) as the primary customer of the power produced. These power purchase agreements (PPA) had a pre-determined tariff rate along with an escalation clause that allowed gradual increases in the rate of electricity purchased from biomass power plants (Autoconsumo energetico 2014). The biomass power tariff is supposed to be revised every year. The Central Electricity Regulatory Commission (CERC) is annually recommending new tariffs to the states based on the public hearings. But the states have right to accept or not the recommendation (Paliwal 2012).

The price of biomass fuel has increased in ten years from 7.1 € (600 Rs) per ton to as high as 35.5 € (3 000 Rs) per ton today (2012), and therefore government tariff policy needs annual revision. The biomass power tariffs (33.1–55.6 €/MWh) are too low to make a reasonable return on the investments (Autoconsumo energitico 2012). In Rajasthan the tariff has increased from 44.0 €/MWh in 2011 to 63.9 €/MWh in 2012. That is not enough, because the electricity production costs were 2012 72.2 €/MWh (6.1 Rs/kWh) in Rajasthan Renewable Energy Corporation Ltd. (RRECL) (Paliwal 2012). Considering the seasonal unavailability of biomass, the government had allowed biomass power plants a maximum fuel mix ratio of 75:25 i.e. 75 % biomass and 25 % coal could be used to feed the plant (Autoconsumo Energetico 2012).

Table 16. Biomass power generation tariffs in different states of India (Bioenergy 2011 and Bioenergy consult 2013).

State	Tariff 2011 €/MWH (Rs/kWh)	Tariff 2012 €/MWh (Rs/kWh)	State	Tariff 2011 €/MWh (Rs/kWh)	Tariff 2012 €/MWh (Rs/kWh)
Andra Pradesh	50.6 (4.28)	49.7 (4.2)	**Punjab**	59.8 (5.05)	62.1 (5.25)
Chattisgarh	52.1 (4.40)	49.7 (4.2)	**Rajasthan**	44.0 (3.72)	63.9 (5.40)
Gujarat	52.1 (4.40)		**Tamil Nadu**	53.3–56.1 (4.5–4.74)	
Haryana	47.3 (4.00)	62.0 (5.24[1])	**Uttaranchal**	36.2 (3.06)	
Karnataka	43.3 (3.66)		**Uttar Pradesh**	50.8 (4.29)	55.6 (4.70[1])
Kerala	33.1 (2.80)		**West Bengal**	51.6 (4.36)	
Maharashtra	58.9 (4.98)	63.9 (5.4)	**Bihar**	49.3 (4.17)	
Madya Pradesh	39.1–60.8 (3.3–5.14)	56.4 (4.77)	**Orissa**	48.4 (4.09)	

[1] Year 2013.

5.2 Biomass price in India

5.2.1 Biomass fuel price development

During the last years many of the biomass power plants have been shut down. The main reason for that is the risen biomass fuel price. Biomass price rises typically very fast after the power plant is commissioned. The price of biomass for energy has increased by 30–40 % every year (Table 17) (Paliwal 2012).

An example of the biomass price increase is from Transtech Green Power Ltd. in Jaipur in Rajasthan. At the first phase, they used Prosopis juliflora, growing wild in the area, as feedstock. The price of Prosopis juliflora was 17.8 € (1 500 Rs) per ton in 2010 but in 2012 the price was 29.6 € (2 500 Rs) per ton. Transtech green power Ltd. has shifted to use mainly cumin husk instead of Prosopis juliflora. The price of cumin husk was 26.0 € (2 200 Rs) per ton in 2012 (Paliwal 2012).

The share of biomass fuel supply costs is remarkable in electricity production costs. The production costs of electricity is at the moment about 72.2 € (6 100 Rs) per MWh (Pelkonen et al. 2013). It is needed about 1 265 kg of agro biomass to produce 1 MWh of electricity assuming that the biomass calorific value (30 w-% moisture) in combustion is 14.2 MJ/kg (3.95 MWh/ton) and power plant efficiency is 20 %. The fuel costs from electricity production are about 29.9 € (2 530 Rs/MWh_e) assuming that the fuel price is 18.9 € (2000 Rs) per ton. The biomass fuel costs (29.9 €) are about 41.4 % of the total electricity production costs.

The price of biomass feedstock varies from state to state. The prices were highest in Maharashtra and Madhya Pradesh and the lowest price was in Andre Pradesh and Rajasthan states. The most expensive biomass is in all states in 2012 is rice husk, 26.0–41.4 € (2 200–3 500 Rs) per ton. Also the price of Prosopis juliflora is high, 22.5–33.4 € (1 900–2 825 Rs) per ton. Saw dust and coconut waste are the cheapest biomass fuels, 14.2 – 24.9 € (1200 – 2100) per ton (Paliwal 2012).

One reason for the increased price of biomass is the increased competition of biomass feedstock in India. Other industrial companies like brick kilns have started to replace their fuel like furnace oil and coal with biomass. The survey of biomass price and supply in Rajasthan state shows that brick kilns are the state’s biggest biomass competitors with power companies. During 2010–2011 kiln owners paid 4.5 € (377 Rs) per ton from biomass more than power plants. The price of coal was 41.6–45.7 € (3 511–3 865 Rs) per ton (Paliwal 2012 and Dalkia Energy Services Ltd. 2011). The average energy content as received of coal in brick kilns is 15.8 MJ/kg (3 790 kcal/kg) and the energy content of biomass as received 14.2 MJ/kg (3.95kWh/kg)

The price of biomass in December 2013 in a biomass plant in Tamil Nadu varied between 11.8–33.1 € (1 000–2 800 Rs) per ton. The power plant paid from the biomass in average about 18.9 € (1 600 Rs) per ton. It seems that the price in 2012 compared to 2013 has not increased anymore so quickly as in earlier years (Pelkonen et al. 2013 and Natarajan et al. 2014).

Table 17. Biomass fuel prices in selected states in India in 2010 and 2012 (Paliwal 2012).

State	Type of fuel	Price (Rs/ton) 2010	Price (Rs/ton) 2012
Maharasthra	Rice husk	18.9-22.7(1600-1920)	33.1-37.9(2800-3200)
	Prosopis juliflora	18.6-20.1(1575-1695)	31.1-33.4 (2625-2825)
	Groundnut shell	19.2-20.2 (1620-1710)	32.0-33.7(2700-2850)
	Mung husk	15.6-16.3 (1320-1380)	26.0-27.2 (2200-2300)
	Coconut waste	8.5-9.6 (720-810)	14.2-16.0 (1200-1350)
Andra Pradesh	Rice husk	15.6-16.3(1320-1380)	16.0-27.2 (2200-2300)
	Maize shanks	14.2-15.6 (1200-1320)	23.7-26.0 (2000-2200)
	Prosopis juliflora	13.5-16.3 (1140-1380)	22.5-27.2 (1900-2300)
	Sawdust	10.7-14.9 (900-1260)	17.8-24.9 (1500-2100)
Rajasthan	Prosopis juliflora	14.2-17.8 (1200-1500)	29.6-30.8 (2500-2600)
	Mustard/cumin husk	14.2-15.6 (1200-1320)	23.7-26.0 (2000-2200)
Madhya Pradesh	Rice husk	21.3-24.9 (1800-2100)	25.5-41.4 (3000-3500)
	Maize shanks	14.2-15.6 (1200-1320)	23.7-26.0 (2000-2200)
	Groundnut shell	19.2-20.1 (1620-1700)	32.0-33.7 (2700-2850)
	Prosopis juliflora	17.0-18.3 (1440-1550)	28.4-29.6 (2400-2500)

5.2.2 Seasonal variation in biomass price

Data on seasonal variation in biomass prices has been carried out in Rajasthan state (Table 18). The price of biomass varies depending on the harvesting season of the crops. The prices are lowest in the period April to June (harvesting period of mustard) for all the plants depending on the mustard residue as a main fuel (table 18).

Table 18. Average biomass price at the gate of one power plant for various different months in 2011 in Rajasthan state (Dalkia Energy Services Ltd. 2011).

Month	January	February	March	April	May	June	July	August	September	October	November	December
Price												
€/ton	33.8			28.6	28.6	27.1	28.5	29.1	36.1	34.1	25.7	32.0
Rs/ton	2860			2415	2416	2290	2405	2462	3050	2881	2175	2706

5.2.3 Breakdown of biomass fuel price

In Rajasthan state it has been collected data from farmer's biomass fuel price from seven districts during 2006 – 2011. The average farmer's biomass average selling price has increased from 8.3 € (705 Rs) per ton in 2006–2007 up to 16.7 € (1 414 Rs) per ton in 2010–2011 (Figure 24). The increase is 100 % in four years. Based on this data the farmer's selling price is the main reason for the high biomass price in India (Dalkia Energy Services Ltd. 2011).

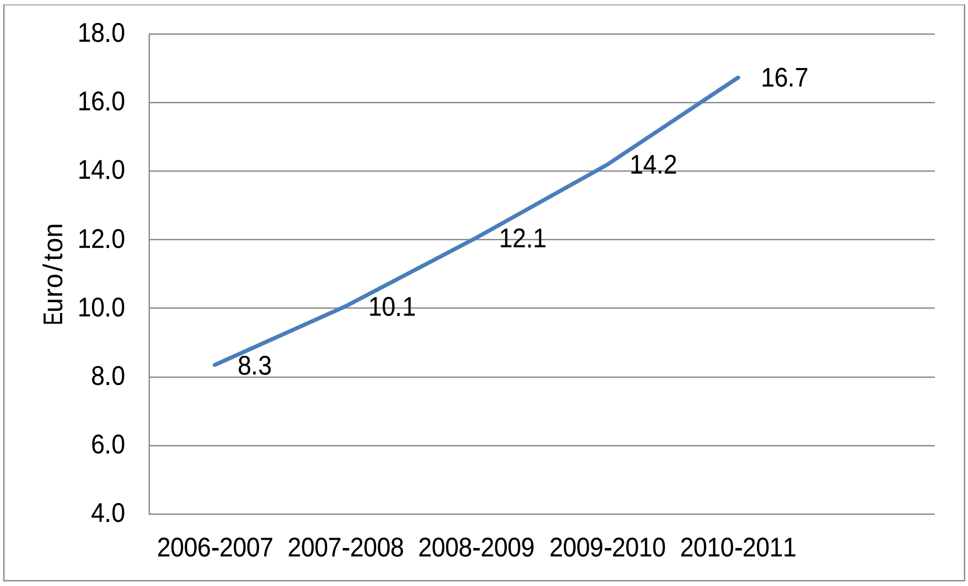

Figure 24. The average farmer's biomass selling price trend in Rajasthan (Dalkia Energy Services 2011).

The average trader's selling price in Rajasthan was 20.8-23.4 € (1 754-1979 Rs) per ton to the biomass plant in 2011 per ton. The share of farmer's price 16.4 €/MWh (1414 Rs/MWh) was 80 % from the total biomass price at the gate. The trader's margin was in average 4.1 € (346 Rs) per ton varying from 2.4–8.0 € (200–675 Rs) per ton in different districts in Rajasthan. The trader's margin (346 Rs/ton) was only about 20 % from the total selling price. The trader's margin includes transport (146 Rs/ton) and storage and handling costs (100 Rs/ton). The real trade profit is only 1.2 € (100 Rs) per ton (Dalkia Energy Services Ltd. 2011) (Table 19).

Table 19. The breakdown of the biomass fuel price in Rajasthan state 2011 (Dalkia Energy Services Ltd. 2011).

Farmer's price €/ton (Rs/ton)	Transport €/ton (Rs/ton)	Storing and handling €/ton (Rs/ton)	Trader's margin €/ton (Rs/ton)	Total biomass price €/ton (Rs/ton)
16.4 (1 414)	1.7 (146)	1.2 (100)	1.2 (100)	25.7 (1 760)

There is also other information of the farmer's price in literature. Based on this information the biomass power plant is paying from cumin biomass about 26.0 € (2 200 Rs) per ton to the biomass supplier. The biomass supplier pays 10.4 € (880 Rs) per ton to the farmer from the biomass, 2.6 € (220 Rs) per ton to workers from procurement, 9.1 € (770 Rs) per ton for transportation and his own profit is 3.9 € (330 Rs) per ton. Especially the share of farmers and biomass suppliers is increased (Paliwal 2012).

5.2.4 Price of Prosopis juliflora

In the state of Rajasthan Prosopis juliflora is available to the power plant from three different sources: (1) from auction by Central Farms under the department of Agriculture, (2) from State Forest Department and (3) directly from traders and farmers (Dalkia Energy Services Ltd. 2011).

The gate price of Prosopis juliflora during 2010–2011 was 22.7–26.2 € (1 915–2 215 Rs) per ton. The share of stump price of Prosopis juliflora (8.6–11.2 €/ton) is 37–43 % of the gate price. The harvesting costs 8.6 € (300 Rs) per ton are 14–15 % from the gate price. The transport, loading and unloading costs 8.8 € (740 Rs) per ton are 33–37 % from the gate price. Chipping costs (2.7 €/ton) are 10–11 % from the gate price (Dalkia Energy Services Ltd. 2011) (Table 20).

Also the price of Prosopis juliflora has increased during the last few years. The price of Prosopis was 21.3 € (1 800 Rs) per ton in 2008–2009, 23.6 € (1990 Rs) per ton in 2009–2010 and 28.1 € (2 377 Rs) per ton in 2010–2011. The increase on three years has been 32 % (Dalkia Energy Services Ltd. 2011).

Table 20. The breakdown of Prosopis juliflora price at the gate (Dalkia Energy Services Ltd. 2011).

Work	Auction by central farms under Agriculture Department €/ton (Rs/ton)	State Forest Department €/ton (Rs/ton)	Direct from traders and farmers €/ton (Rs/ton)
Stump price	14.8 (1 250)	8.6 € (730)	22.5 (1 900)
Cutting cost by contractor	included above	3.6 (300)	included above
Transport cost – 75 km	7.1 (600)	7.1 (600)	Included above
Loading and unloading cost	1.7 (140)	1.7 (140)	included above
Chipping cost at the plant	2.7 (225)	2.7 (225)	2.7 (225)
Total	26.2 (2 215)	25.3 (2 135)	27.7 (2 338)

5.2.5 Briquetting costs

In Rajasthan state it has been collected data on biomass briquettes from different states in 2011. The price of raw material for briquette production was 16.6–27.2 € (1 400–2 300 Rs) per ton. The sale price of briquettes were 29.9–42.2 € (2 530–3 565 Rs) per ton. Thus briquetting increases the price by 55–80 % (Dalkia Energy Services Ltd. 2011).

6. Bioenergy potential and use in focus states

6.1 Renewable power potential in focus states

The target of the project is to analyse the biomass supply in general in whole India and more precisely in Tamil Nadu, Madhya Pradesh and Maharashtra states (Figure 25). In the selected states there is a lot of biomass potential (Table 21), a lot of industry and a lot of interest for bioenergy. In the focus states there is also other renewable energy potential beside the bioenergy (Figure 26) (MSPI 2014).

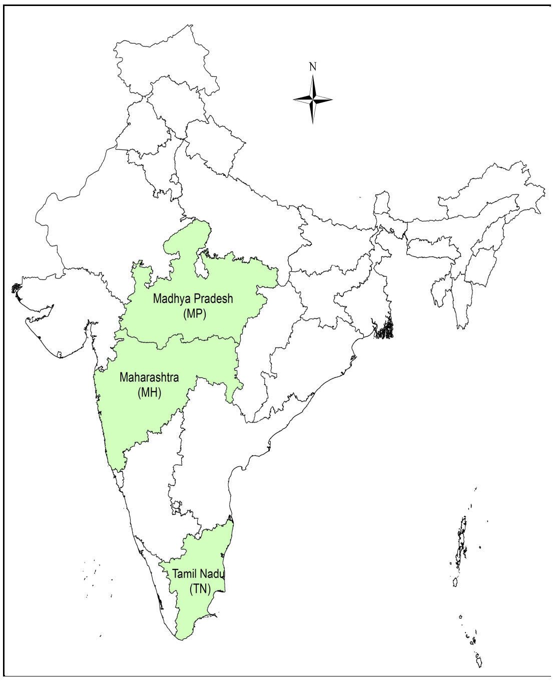

Figure 25. Focus states at the map.

Table 21. The total Biomass potential in Tamil Nadu, Madhya Pradesh and Maharashtra states in 2002–2004 (CGPL 2014).

	Tamil Nadu MWe	**Madhya Pradesh MWe**	**Maharashtra MWe**
Agro biomass	1160.0	1373.3	1983.7
Biomass from wasteland	105.8	965.5	1024.4
Forest biomass	324.0	752.5	717.3
All together	1589.8	3091.3	3 725.4

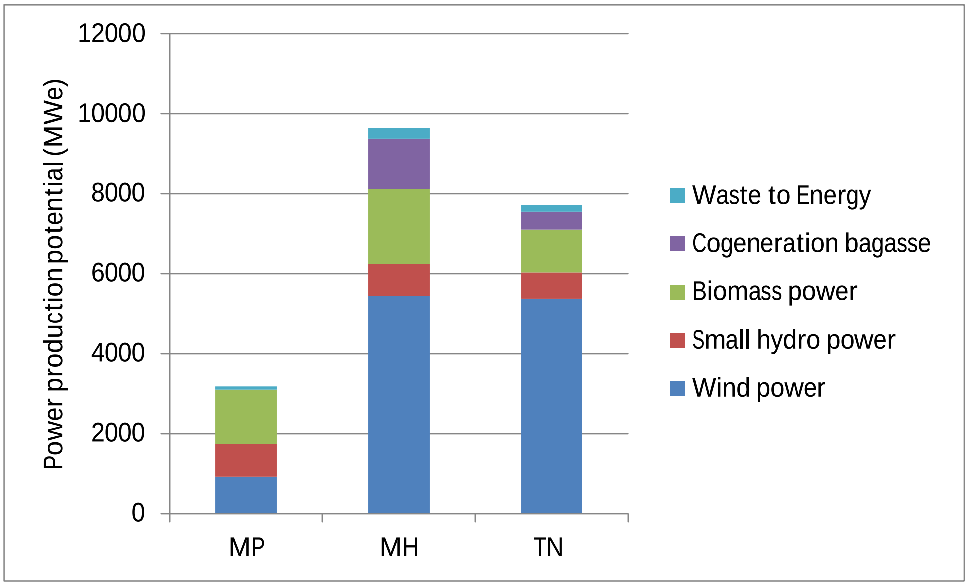

Figure 26. Renewable power production potential in three states (MSPI 2014).

6.2 Biomass potential and current use in Tamil Nadu

The total biomass power potential in Tamil Nadu was 1589.8 MWe in 2002–2004 (Table 21). The total agroindustry biomass power potential in Tamil Nadu state is high, 1 160.0 MWe (Table 21). In Tamil Nadu there are many different kind of agro biomass types available for energy use. The main agro biomass residues are paddy straw and paddy husk, maize stalk and husk, groundnut stalk and shell and cotton stalk (Table 10). The total wasteland area in Tamil Nadu is 7 549 km^2. The potential of biomass residues from wasteland is 106 MWe representing about 0.77 million tons of stalks, branches, leaves, twigs and bark of different logging operations of bushes and trees. There is a lot additional biomass power potential cultivating energy crops as a fuel on wasteland. The forest biomass power potential is 324.0 MWe (CGPL 2014).

The total installed electricity production capacity in Tamil Nadu state was 7 405 MWe in 2011 (TEDA 2014b). The total installed biomass and cogeneration in sugar mills power capacity in Tamil Nadu was 659.4 MWe in 2014. From this the biomass electricity capacity was 226 MWe (TEDA 2014a). In the installed power plants the main biomass is agroindustry residue. This means that the consumption of biomass for energy in Tamil Nadu is about 1.7 million tons assuming that the energy content of biomass as received is 3.95 MWh/ton and the electrical efficiency is 20 %. Most of the plants are located in the south of Tamil Nadu where adequate biomass from agriculture and wasteland is available (Figure 27).

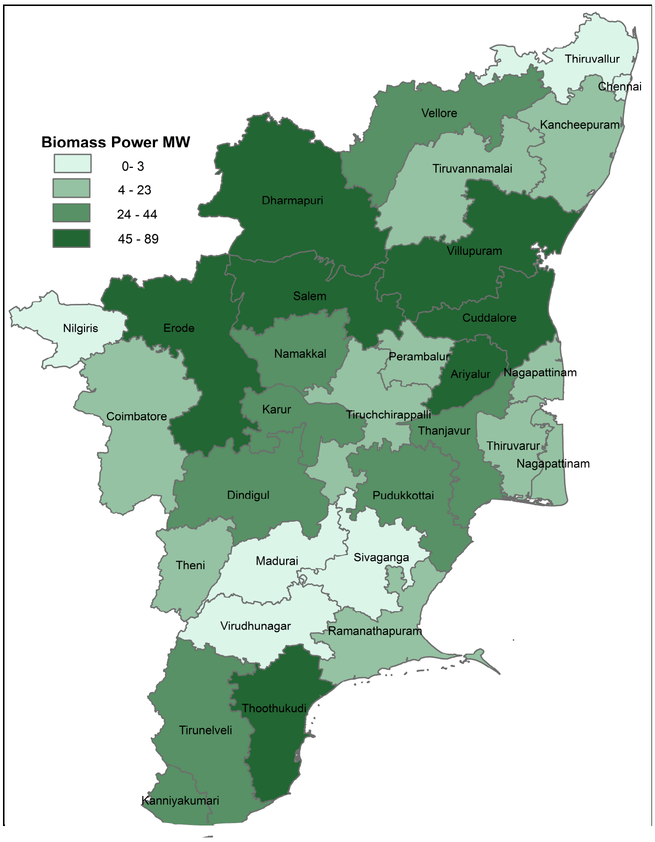

Figure 27. District wise biomass power potential in Tamil Nadu state (TEDA 2014).

6.3 Biomass potential and current use in Madhya Pradesh

The total biomass power potential in Madhya Pradesh was 3091.3 MWe in 2002–2004. The agro biomass power potential (1373.3 MWe) is nearly 50 % from the total biomass power potential. The rest of the biomass power potential is covered by biomass from wasteland (965.5 MWe) forest biomass (752.5 MWe) (Table 21). The highest biomass potential in Madhya Pradesh is located in the southwest (CGPL 2014) (Figure 28).

At the moment the use of biomass for energy is minor even though there are many of sugar mills in Madhya Pradesh. The State Government has implemented ‘Biomass policy-2011’ to promote setting up of biomass based power plants in Madhya Pradesh. So far, 40 MWe capacity biomass power plants have been set up in the state. At present, projects of 308 MWe capacity are under construction (Department of public relation of Madhya Pradesh 2013).

At present, 474 MWe power is being generated by renewable energy sources, which is 5.3 percent of the Madhya Pradesh state’s total power generation capacity. Due to efforts of State Government, this capacity is going to increase to 2 500 MW by December 2014, which will be 17 percent of the state’s total power generation capacity (Department of public relation of Madhya Pradesh 2013).

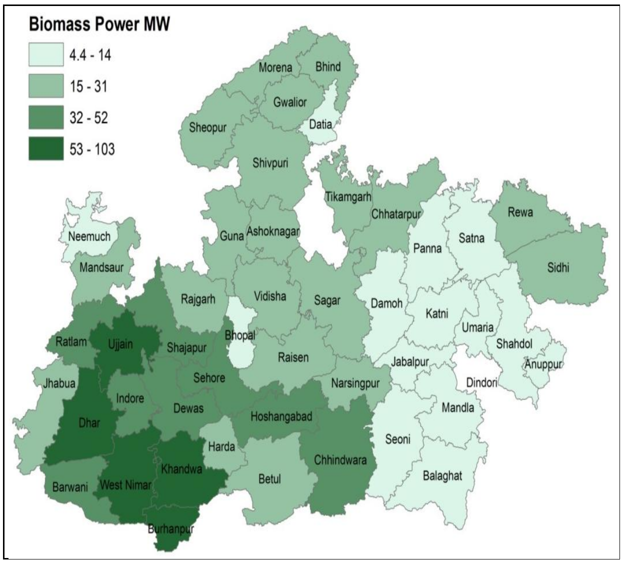

Figure 28. District-wise biomass power potential in Madhya Pradesh (MPREDA 2014)

6.4 Biomass potential and current use in Maharashtra

The total biomass power potential in Maharashtra is 3 725.4 MWe. The share of agro biomass power potential (1983.7 MWe) is 53 % from the total biomass power potential. The rest of the biomass power potential consists of biomass from wasteland (1024.4 MWe) and forest biomass (717.3 MWe) (CGPL 2014) (Figure 29).

The installed biomass power and bagasse CHP capacity in Maharashtra is 403 MWe in 2011(Pothan 2012). The installed biomass power capacity in Maharashtra was about 180 MW in 2013. The number of biomass power plants was 17 in 2012 (Bioenergy consult 2013, Paliwal 2012 and MEDA 2014).

In Maharashtra there is a lot of interest on CHP power plants. The concept of simultaneous generation of electricity and thermal energy is called cogeneration. It produces two forms of energy from a single fuel source. One of the forms of energy must always be heat and the other may be electricity or mechanical energy (Green clean guide 2012).

As per the cogeneration association of India, there are many industrial sectors that have good potential for cogeneration. Industrial units in following sectors should take advantage of cogeneration technology – Sugar, Paper, Oil Extraction, Urban Waste Treatment, Forest based Industries, Chemicals Fertilizers, Metallurgical Industries, Textiles-Cotton & Synthetic, Hotels, Rice Milling, Food Processing, Rubber Industries, Petroleum & Refineries and Malt & Brewery Industries (Green clean guide 2012).

In Maharashtra, most of the cogeneration plants are developed by Sugar factories as they have enough quantity of bagasse – a by-product of sugar production. Therefore mostly all sugar factories involve cogeneration system which use bagasse as fuel (renewable source of energy) in order to meet power and steam requirements of the production process. Besides this, it also provides excess power to the grid or use for other purpose like captive consumption for other industrial use (Green clean guide 2012).

Promotional policy for the cogeneration and other biomass based power projects by the Government:

- Indian Renewable Energy Development Agency (IREDA) provides loan for setting up biomass power and bagasse cogeneration projects.
- The Ministry of New & Renewable Energy (MNRE) has been supporting the Cogeneration power projects by giving back ended subsidy. The 50 % subsidy will be released for sugar factories developing Cogeneration power projects in cooperative sector / public sector /government under taking/ SPV company (Urja Ankur Trust) through BOOT model after issuance of purchase orders for larger equipments like boiler, turbine etc. The remaining 50 % subsidy could be availed after commissioning of the project and demonstrating its continuous operation for 90 days (3 months) from which 72 hours the plant should run with 80 % PLF.
- For private sector, a one-time subsidy will be released after commissioning of project after assessment of performance of the plant.
- Overview of Renewable Energy Certificates: Renewable Energy Certificates are a type of environmental commodity intended to provide an economic incentive for electricity generation from renewable energy sources. One REC is created when one megawatt hour of electricity is generated from an eligible renewable energy resource. REC represents the environmental attribute associate with unit of power produced.
- Eligibility of cogeneration power plants under the REC mechanism: If sugar mill has a biomass cogeneration based power plant, they are eligible to earn RECs subject to these power plants are grid connected and have PPA with DISCOM at APPC price (As per the CERC guidelines, the power producer has to sign a PPA with the state utilities at a price equal to the Average Power Purchase Cost price. The APPC price for a state for a particular time period is determined by the State Electricity Regulatory Commissions). Grid connected cogeneration power plants that provide electricity for captive uses are also eligible to earn Renewable energy certificates (REC).

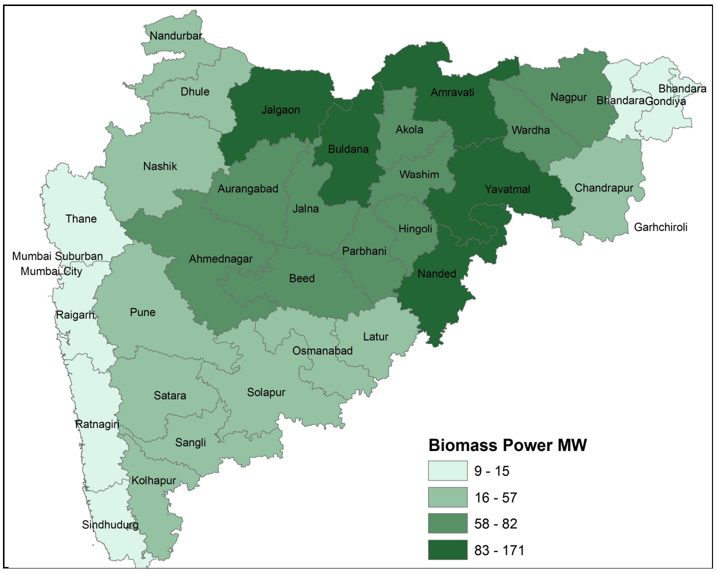

Figure 29. District-wise biomass power production potential (MWe) in Maharashtra state (CGPL 2014).

7. Current biomass power potential and use in pilot districts in focus states

7.1 Introduction

In order to study the existing practice of agricultural biomass utilisation, two pilot districts are identified in each state. They are Bhopal and Indore in Madhya Pradesh Thane and Pune in Madhya Pradesh and Kancheepuram and Coimbatore in Tamil Nadu. Seventy five farmers divided in to three categories (small, medium and large land holding) in each pilot district were randomly selected for survey. The structured questionnaires include questions on crop production, average annual biomass generation, current practices on biomass utilization, and surplus biomass available for supply.

7.2 Biomass potential and current use of agricultural residues in pilot districts

The share of biomass consumption and surplus availability in Tamil Nadu, Madhya Pradesh and Maharashtra varies geographically depending on many factors: crop production, crop types, seasonal variations, available infrastructure, cultural and traditional practices (Figure 30).

The various existing traditional practices in the agro-biomass utilization are presented in the figure 31. Agricultural residues are used for roofing, animal fodder and cooking in households. But also it is burnt on the field or dumped on the road side.

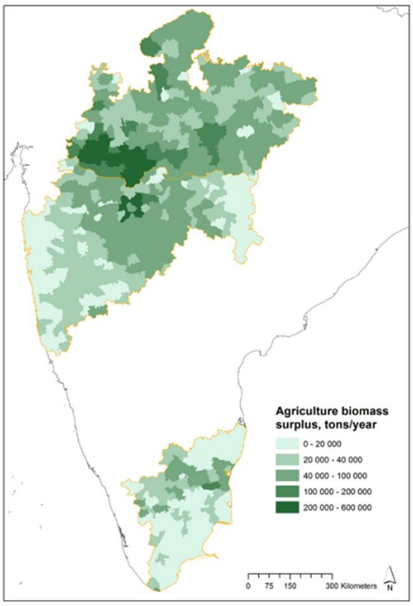

Figure 30. Surplus agro-biomass availability in Madhya Pradesh, Maharashtra and Tamil Nadu (Käyrä 2014).

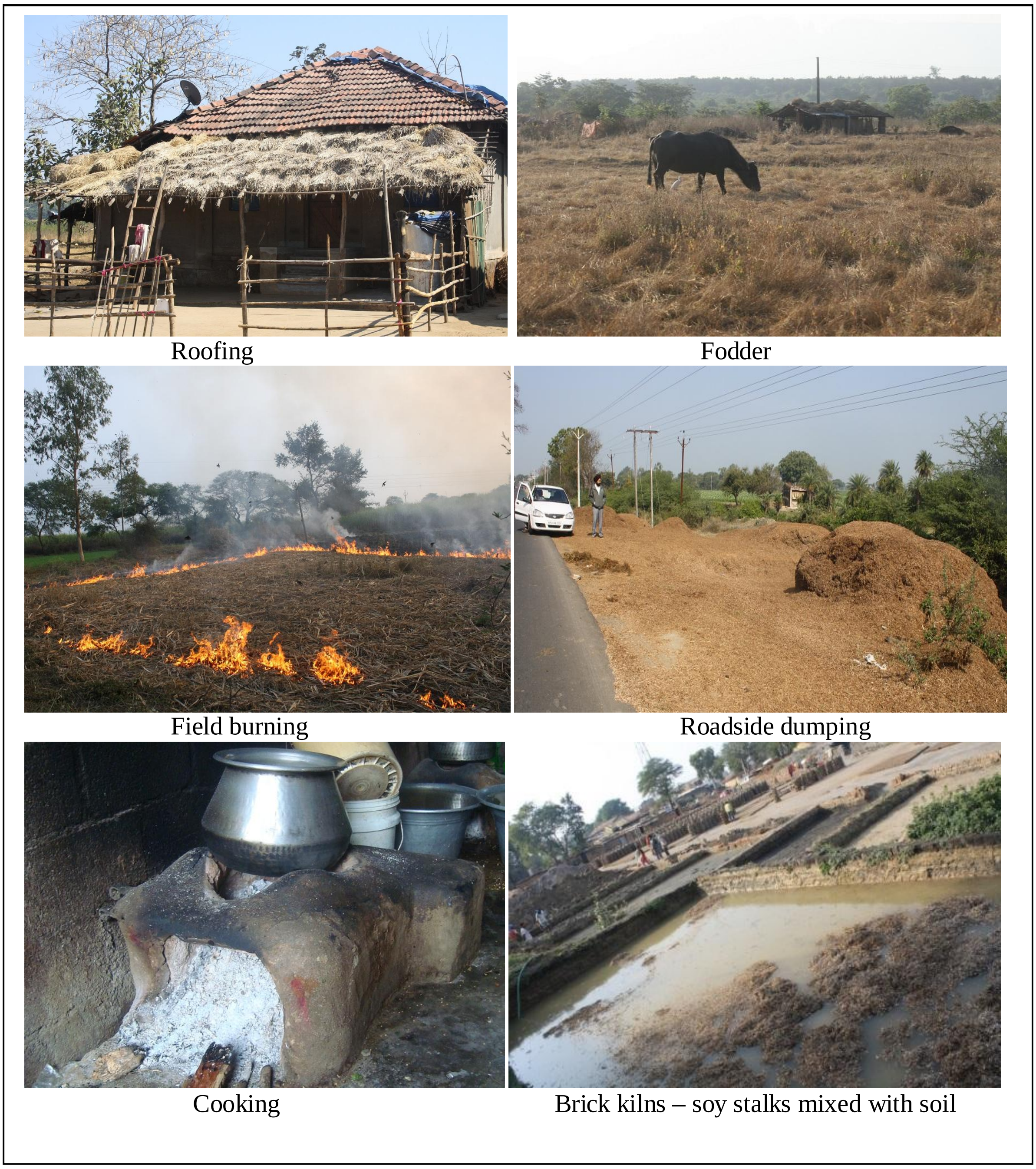

Figure 31. Current traditional practices of agro-biomass utilization.

The collected results show that agro-biomass for fodder is the predominant use of agricultural residues in all the selected study districts except Coimbatore (Figure 32). This is due to the reason that in Coimbatore the major agricultural crop residuals are from groundnut, tapioca, and cotton where they are usually field ploughed to enrich the soil fertility as manure. The agricultural residuals such as sorghum stalks, paddy straws, and maize stalks are collected and used as fodder. The major buyers for agro-biomass are dairy farms and small industries like brick kilns.

The traditional practice of field burning is common in Madhya Pradesh in order to prepare the field for next sowing season in a quick span of time. This is because the collection window for biomass is rather short between two crop seasons in Madhya Pradesh. Besides field burning, the soybean residuals are also dumped out at the roadside in Madhya Pradesh. One can think that the biomass burnt in the field /roadside dumping could be also harnessed for future energy generation through well-organized supply chain. Moreover, all the selected six districts have minimal use of biomass for coking as the farmers have access to modern LPG cooking stoves.

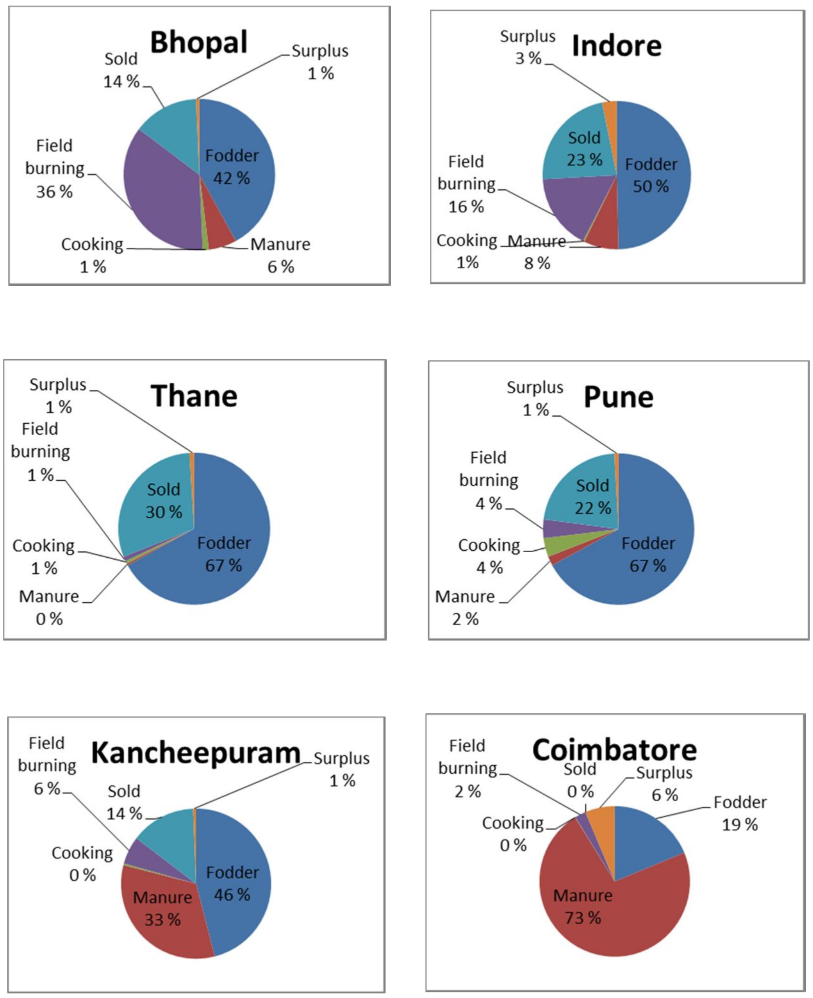

Figure 32. Share of biomass consumption and surplus availability in six pilot districts.

7.3 Current use of forest biomass in pilot districts

The potential of utilizing forest biomass for energy generation exists but not utilised in its entirety. The degraded forest lands offer an excellent opportunity to raise plantations which would also increase the livelihood opportunities to the local community through Joint Forest Management practices. However, the challenges to harness the forest biomass for energy generation are manifold e.g., inaccurate data on forest land resources, encroachment, strong conservation acts and policies, wildlife, remote areas and poor infrastructure. It is estimated that 59.7 million tonnes of surplus forest biomass can be generated annually in whole India (CGPL 2014). The state wise forest biomass generation potential was 5.4 million tonnes in Madhya Pradesh, 5.1 million tonnes in Maharashtra and 2.3 million tonnes in Tamil Nadu (CGPL 2014). The state wise taluk level forest biomass distribution is presented in the figure 33.

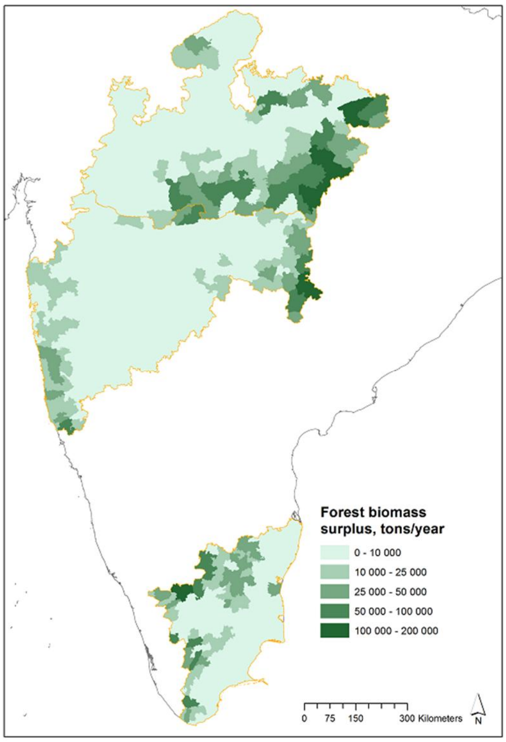

Figure 33. Surplus forest-biomass availability in Madhya Pradesh, Maharashtra and Tamil Nadu (CGPL 2014).

7.4 Current use of industrial biomass

There are various industries such as saw mills, rice mills, jaggery plants and sugar mills, which generate industrial biomass residuals as by-product/wastes. The industrial biomass is partially or fully consumed by the producer and/or also sold to the market at a competitive price. The availability of industrial residuals and its existing use in six pilot districts (Bhopal, Indore, Thane, Pune, Kancheepuram and Coimbatore) was estimated through the field survey. Sawmill residuals from sawmills, rice husks from rice mills, sugarcane bagasse from sugar mills and jaggery plants is the major industrial biomass available for energy generation (Figure 34).

Wood chips/shavings - Sawmills

Sugarcane bagasse - Sugar mills

Rice husks – Rice mills

Sugarcane bagasse – Jaggery plants

Figure 34. Industrial wood and agro resides.

Maharashtra and Tamil Nadu are the leaders in bagasse based co-generation in India. There exists a clear co-generation policy and action plans to realise the co-generation projects in sugar mills. However in Madhya Pradesh, there is a potential to collect bagasse from existing sugar industries since there are not many co-generation units are installed yet. The bagasse generation ratio is approximately 30 % (100 tonnes of sugarcane produces 30 tonnes of bagasse). In jaggery plants the bagasse generated during juice extraction process is then used as fuel in the jaggery manufacturing process and therefore, the surplus biomass availability is nil.

Similarly, wood chips/shavings from sawmills can be utilised in power generation together with agro-biomass. The capacity of sawmills located in the six districts varied greatly. Based on our field visits, the calculated average capacity of sawmills ranges between 1.5–3 m^3/day round wood input. On average, sawmills can produce 2-4 tons of saw dust per month and 3-6 tons of wood chips/end cuts per month. At present, the saw mill residuals are sold to hotels, bakeries/tea shops, poultry farms and brick kilns. Table 22 presents the general information on the sawmill residual potential in the six districts.

Table 22. Sawmill residuals in six selected districts.

Type	Bhopal	Indore	Thane	Pune	Kancheepuram	Coimbatore
No of sawmills	130	220	150	400	1200	350
Wood input (t/y)	10 800	16 800	17 100	266 700	695000	500 500
Saw dust and wood shavings (t/y)	2 400	3 300	800	7400	36 000	26 200
Wood chops and end cuts (t/y)	2600	5500	3 800	11,600	50 300	35 700
Price (Rs/ton)	2500-3500	2500-3500	4 000	3 500-4000	2 500-3500	2500-3900

Source: Industrial survey and interviews

The rice mills are distributed in the nearby areas of agricultural areas where paddy is predominantly cultivated. For e.g., Thane, Kancheepuram and Coimbatore are predominantly paddy cultivable regions. In practice, the rice husk generated from these mills is sold to local restaurants, furnaces, parboiling process, brick kilns and plywood industry at a price of 3000 Rs/ton. Table 23 presents an overall estimate on number of rice mills and rice husks generated in the six districts.

Table 23. Rice husks generation in the six selected plot districts.

Type	Bhopal	Indore	Thane	Pune	Kancheepuram	Coimbatore
No of rice mills	10	10	150	50	350	175
Rice processed (t/a)	53 000	75 000	180 000	40 000	159 000	29 400
Rice husk produced (t/a)	10 500	16 000	45 000	10 000	31 800	5 880
Price (Rs/ton)	3 000	3 000	3 200	3 000	3000	3 000

Source: Industrial survey and interviews

7.5 Industrial competition

The brick kiln industry is one of the most unorganized industrial sectors in India. The fuel share in brick kiln depends on the type of brick produced, fuel availability, fuel costs and traditional practices. In brick kilns, biomasses are used as additive agent (mixed with soil to increase the brick strength) and fuel (kiln process). This practice varied from place to place. For instance, soybean stalks are used as additive agent in Madhya Pradesh whereas rice husks are used as additive agent in Madhya Pradesh. Contrastingly, Tamil Nadu brick kilns do not use biomass as additive agent. The figure 35 presents the overview of fuel share in the surveyed brick kilns of Madhya Pradesh, Maharashtra and Tamil Nadu. One should take in to account that there is a great uncertainty on the estimation of biomass demand at brick kilns since the fuel share varies greatly between kilns at a given location.

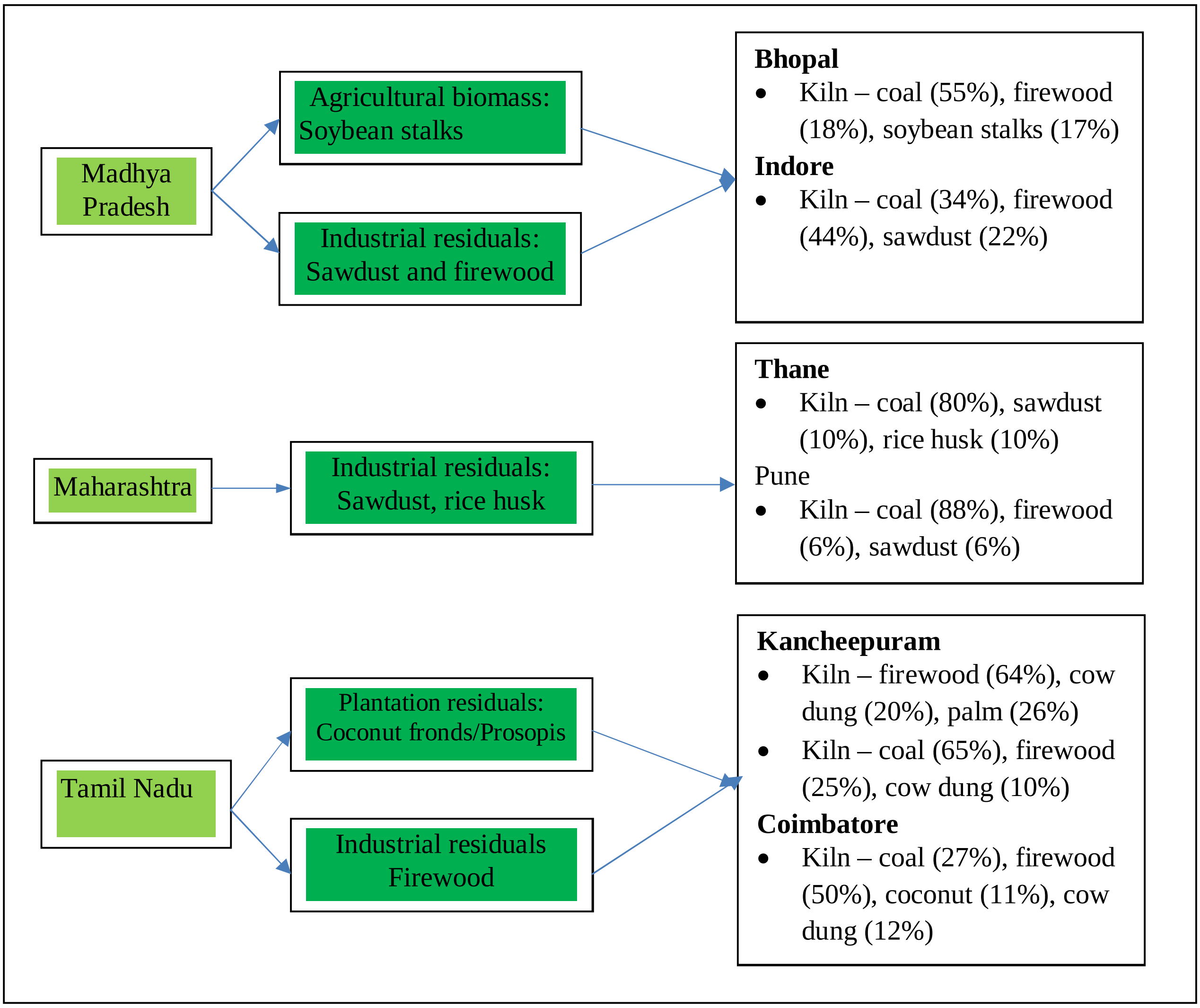

Figure 35. Biomass use in brick kilns in Madhya Pradesh, Maharashtra and Tamil Nadu.

7.6 Challenges and opportunities

Most Indian cities face acute power shortage which is exacerbated by fluctuating fossil fuel costs and growing demand for more power due to rapid urbanization. The biomass based power holds great potential to support India’s growing energy demand but it is not utilised in entirety. Constraints related to resource availability, supply chain logistics and infrastructure, technological modifications, and lack of strong legislative and financial measures have resulted in the poor attraction of biomass power investments in India.

The current traditional practices on various uses of biomass have limited the availability of biomass supply to the energy generation. However, it will be unrealistic to collect the biomass for energy generation without meeting the existing demand. Particularly, the biomass dependency for fodder production is high in India. Therefore, it is imperative to utilise non-fodder crops (e.g., soybean husks, cotton stalks, coconut fronds) for energy generation. On the other hand, the biomass dependency for domestic purposes (cooking, thatching) could be reduced through modern cooking stoves (improved cooking stoves, subsidised LPG) and government housing programmes. This would not only reduce the biomass dependency but also improve the people life style and healthy living.

An organized biomass market is a key for the successful development of biomass industry in India. Particularly an uncontrolled biomass price increase has been a major factor for shutting down many biomass power plants across the country. The present biomass industry lacks a successful stakeholder model for sustainable utilisation of biomass for energy generation. For example a biomass power plant depends on many geographically dependent factors like continuous biomass supply, quality and mix of biomass, biomass price, power evacuation infrastructure, labour availability, public acceptance, water resources, industrial competition and co-operation between governmental departments. The variations in any one of the factor would greatly have an effect on the plant operation. Besides these factors, the commercial implications of renewable energy is very high compared to risks involved in other purchase options such as that of conventional power projects. The main bottlenecks for commercial acceptance of biomass power plants are related to tariff levels, infrastructure funding and balancing costs.

The organized biomass supply chain is crucial to secure the biomass supply. The agricultural biomasses are bulky in nature and therefore, an efficient supply chain is crucial to increase the cost competiveness and energy efficiency. One could select appropriate fuel collection methods like bundling (paddy straw, sugarcane tops), chipping (e.g eucalyptus, casuarina) with respect to fuel type which eventually allows more biomass to be transported in a single truck. Subsequently, the biomass could be further processed using fuel processing technologies like pelleting, briquetting to increase the energy efficiency of the fuel. In addition to its increased energy value, the fuel handling becomes easier and then the biomass can be efficiently transported to longer distances.

The sustainability of biomass for energy must be evaluated in detail with respect to food security, environmental performance and energy efficiency. Importantly, country like India cannot afford to have pure energy plantations in agricultural lands which would eventually increases the food competition and food prices. On the other hand, agroforestry practices (where agriculture and energy crops are cultivated together) could be adapted to meet agricultural and biomass production.

8. Current biomass supply chains in focus states

8.1 Orient Green Power Ltd. -biomass power plant in Tamil Nadu

8.1.1 Introduction

The Orient Green Power Ltd. biomass plant is located at Kariyanchettipalayam village which is about in Pollachi taluk in Tamil Nadu. The biomass plant is owned by Orient Green Power Ltd. (OGPL). The size of the power plant is 10 MW_e. Power plant is using about 100 000 tons of different kind of biomass annually (Pelkonen et al. 2013).

8.1.2 Biomass fuel types

The plant uses almost all kinds of biomass fuels that are available for supply. The biomass used at the plant depends on the seasonal availability and biomass price. They are coconut fronds, coconut husks/shells, plywood veneer by-products, medicinal plant residues, groundnut shells, chicken litter, Prosopis juliflora, wheat stalks, mulberry stems, rice husk, palm oil cones/sponges (after oil extraction) and etc. (Figure 36–38).

The most predominant biomass used at the plant is coconut fronds being around 50–60 % of the total fuel share. The power plant is located strategically to utilize the abundant coconut plantation by-products (coconut fronds and coconut husks). The coconut frond generation around the power plant site is estimated to be around 642 800 tons per year while the consumption including the Orient power plant is around 410 000 tons per year.

The power plant has a separate research and development unit focusing on developing fast growing energy crops. They were investigating many different kind of energy crops like Giant reed grass, Giant king grass, Glyrecedia sepium etc.

Figure 36. Coconut frond and mulberry stalks (photos by Arvo Leinonen and Karthikeyan Natarajan).

Figure 37. Palm oil seed bunche (left) and coconut shell (right) biomass (photos by Arvo Leinonen and Karthikeyan Natarajan).

Figure 38. Plywood residues (left) and sawmill residues (right) (photos by Arvo Leinonen and Karthikeyan Natarajan).

8.1.3 Biomass supply chain

Generally the biomass is procured at the farm by the farmer. The procured biomass is delivered and sold to the power plant from the farm by the biomass supplier (trader). Sometimes farmers sell and transport the biomass directly to the power plant with their own vehicle (Figure 39). The power plant pays to the registered suppliers in 30 days from the delivery date.

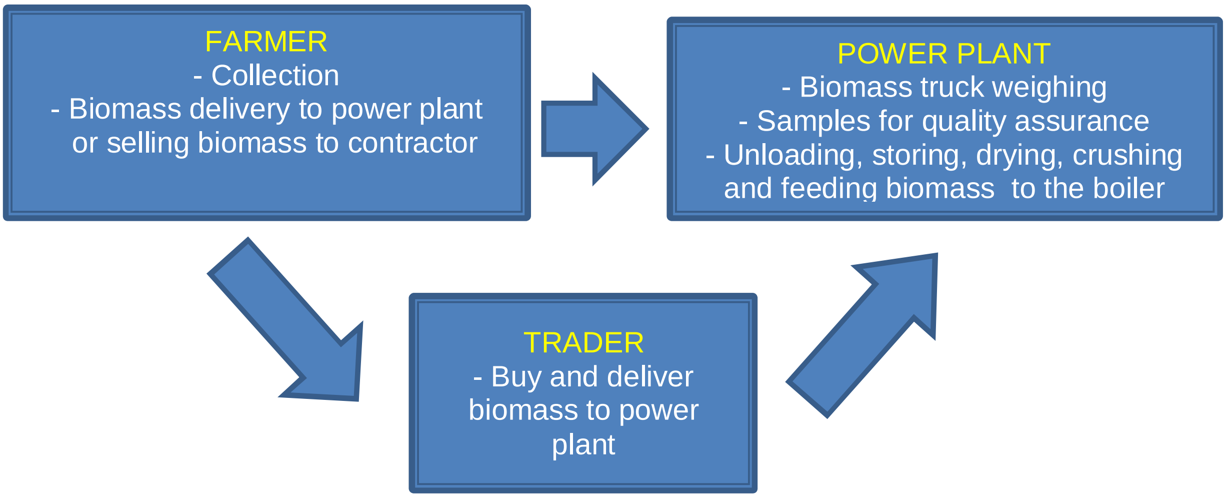

Figure 39. Biomass supply chain to the power plant.

8.1.4 Coconut frond collection

The farmers from biomass is delivered to power plant are very small – only few hectares. There were all together 300 farmers involved in the biomass supply to the power plant. The coconut fronds were the main fuel of the power plant. Coconut fronds are the stiff mid-ribs (stem) of the coconut leaves. The coconut fronds are separated manually by axe from the leaves. Leaves are used for instance for basket production.

Coconut trees are falling every year about 11 leaves on the ground. The coconut fronds are collected manually into small heaps at the farm beside the road (Figure 40). The coconut fronds are dried in the heaps. From the farm the coconut fronds are loaded in the lorries by which the biomass is transported to the power plant (Figures 41).

Roughly 173 coconut trees are planted on one hectare of land. Each tree gives approximately 12 coconut fronds per year (1 frond per month) weighing each 6–8 kg of wet biomass. The annual yield of coconut frond is 14–18 wet tons per ha per year. The initial moisture content of coconut frond is 50–60 %. The coconut fronds are priced at the field between 8.3–11.8 € (700–1000 Rs) per 1000 fronds depending on the size.

Figure 40. Coconut fronds (right) at coconut farm (Photos by Arvo Leinonen.

Figure 41. Loading of coconut frond loaded into the truck at coconut farm (Photo by Arvo Leinonen).

8.1.5 Biomass road transport to power plant

The transportation of biomass from the supply site to the power plant is rather cumbersome process. There is no one supply method or transport vehicle to transport the biomass from the farm to the power plant. There are four - five different vehicles used for biomass transport. They are smaller (2–3 tons payload), big truck with tipping device (9 tons payload), big truck without tipping device (12 tons payload) and tractor trailer (Figure 42).

The biomass procurement methods depend on the vehicle used for the transport. The smaller vehicles like small autos allow the biomass supplier to collect coconut fronds directly into the vehicle from the coconut plantations even in poor road conditions. Generally, the coconut fronds before collection are gathered collected in small heaps at coconut plantation.

All together there were 200 vehicles transporting biomass to the power plant. The transport distance of plywood residues was very long, 200 km. The plywood residues were transported from the neighbour state Kerala. On longer distances it was used bigger lorries (12 tons). The transport distance of coconut frond was about 20 km. The transport distance of small truck was only 20 km. All the vehicles were not transporting biomass every day to the plant. The lorries were weighed with the load and without the load at the gate using lorry scales in order to measure the payload of the lorry (Figure 43).

The payload capacity of the vehicle is limited by the bulk density of the agro biomass fuels. For instance a lorry transporting 20 tons of coal can carry only 4–5 tons of agro biomass. The small density of biomass increases the transport costs. The fuel consumption in truck transport varies from 7 l/100 km to 25 l/100 km.

Figure 42. Trucks and tractors used for biomass road transport (Photos by Arvo Leinonen and Karthikeyan Natarajan).

Figure 43. Biomass payload is weighed at the gate using lorry scales (Photo by Arvo Leinonen).

8.1.6 Unloading of lorries

The lorries were unloaded manually or mechanically (Figure 44). The plywood residues were unloaded manually directly to the crusher from the lorry. The biomass suitable directly for combustion was unloaded from the lorry by excavator on the stockyard from where it was fed to the boiler conveyor. Also bigger lorries were equipped with the tipping device. Wet biomass like coconut fronds were unloaded manually on the biomass handling and storage area.

Unloading of lorries is usually carried out by the biomass supplier. Unloading and loading crew consisted of three men. The costs of three men is 3.6 € (300 Rs) per trip of unloading and loading working phase.

Figure 44. Manual unlaoding of plywood biomass directly to the crusher (left) and unladoing of sawmill residues by excavator (right) (Photos by Arvo Leinonen and Karthikeyan Natarajan).

8.1.7 Biomass storing and drying at power plant

Power plant had a fuel handling yard where biomass were stored, dried and comminuted (Figure 45). The target is to dry the biomass material at the yard up to 40 % moisture content. The material was dried in low layers or in the heaps. It takes several days to dry biomass from 60 w-% down to 40 w-% moisture content at the yard in low drying layer. The fuel layer depth in field drying is approximately 0.6 m. In the heaps it takes one to two weeks to dry biomass at the yard down to 30–40 w-% moisture content. The biomass storages were also used as buffer storages for the time when there were disturbances in supply chain.

Figure 45. Covered and uncovered biomass stockyard (Photos by Arvo Leinonen and Karthikeyan Natarajan).

8.1.8 Biomass comminution

There were two drum chippers at power plant's biomass handling area. Most of the biomass like coconut fronds and some plywood residues were comminuted at the plant. The biomass is mostly comminuted at the power plant. Coconut fronds, plywood residues and other fuels are comminuted processed using drum crushers (Figure 46). The electricity used for chippers was provided by the power plant. Four - seven persons are employed for operating either one the drum chippers or crushers. The costs of comminution operation for plywood residues are 0.65–1.8 € (55–150 Rs) per ton.

Also the plant owns a mobile tractor with mounted disc chipper outside the power plant (Figure 46). The rotation speed of the chipper's drum is 1 500 rpm and the price of the chipper is 2 400 € (200 000 Rs). The productivity of mobile tractor mounted chipper is 2 tons/hour for dry coconut fronds (20–25 w-%) and 4 tons/hour for wet coconut fronds (45–60 w-%). The diesel consumption of the disc chipper is about 4.5 l/hour.

Figure 46. Coconut frond comminution with stationary crusher (left) at biomass yard and mobile chipper (right) outside the power plant area (Photos by Arvo Leinonen and Karthikeyan Natarajan).

8.1.9 Price of biomass fuels

For the quality parameters measurements the samples were taken from every load delivered to the power plant. First five samples (500 g) are taken from the top, bottom, right, left and centre corner of the load in the vehicle. Then the collection sample is crushed and the representative sample (30 g) is used for the laboratory analysis. The laboratory results are available in four hours. From the samples it was measured the moisture content, gross calorific value (GCV) and ash content. The limits for the moisture content at the gate for the moisture content of biomass was 50 w-% and for the ash content 5 w-%.

The grain size of the biomass after chipping was high (Figure 47). The maximum length of grains was about 250 mm. The bigger particles did not burn properly in the boiler. Some unburnt pieces were seen in the bottom ash of the boiler.

The price of biomass decreased at the gate if the moisture of biomass was over 50 w-% and ash content more than 5 w-%. Also the type of biomass and transport distance of the biomass has an impact on the biomass price (Table 24). The biomass plant gate price includes biomass harvesting, loading, transportation, unloading and fuel processing at the plant (not in every case). The gate price of biomass was between 11.8–33.1 € (1 000–2 800 Rs) per ton (Table 24).

Figure 47. Grains size of biomass after comminution (Photo by Arvo Leinonen).

Table 24. Fuel prices and other parameters of different biomass fuels from Orient power plant in Tamil Nadu.

Biomass type	**MC %**	**GCV kcal/kg**	**Ash Content %**	**Biomass cost € (Rs)/ton**	**Transport distance km**	**Quantity tons/a**	**Collecting window months**
Coconut fronds	40		5	11.9 (1000)	20		
Plywood/veneer wood residues	25-35			20.1 (1700)	50-180		
Rice husk	2 5- 30			24.9 (2100)			
Rice (uncooked)	15			33.1 (2800)		30 - 50	
Maize cobs		4000		24.9 (2100)			May - July
Medicinal plant residues	50 - 60	3800		17.2 (1450)	50-180		
Prosopis juliflora				26.0 (2200)	100-280		Nov - Jan
Chicken litter					400		
Napier grass				16.6 (1400)			

8.1.10 Biomass plant

The plant was commissioned on 2011. The power plant is located at an area of 45 hectares area surrounded by coconut plantations. Orient green power is a pioneer in biomass based power production in India owning up to 11 biomass power plants across India. From the biomass power plants the company owned 3 power plants in Tamil Nadu. It is the biggest biomass electricity producing company at the moment in India. Three more power plants are at the commissioning stage. The location for the power plant in Pollachi was selected because of abundant availability of coconut residues and potential of biomass procurement from neighbouring state Kerala.

Currently the electricity is sold to the private industries and government. The electricity price for the industries were 82.8–118.3 € (7 000–10 000 Rs) per MWh. The government price for electricity is around 66.3 € (5 600 Rs) per MWh. The power plant had to pay service fees for power transmission sold to the Tamil Nadu Electricity Board (TNEB). The power plant got a carbon credit from the produced electricity at the plant. Value of carbon credit was 17.85 € (1 500 Rs) per MWh (Table 25).

The power plant faces challenging issues during the rainy season where water logging is common around the fuel yard. Additionally coconut fronds/husks are highly hygroscopic and therefore the increase of moisture content in the storage is a big problem. The maximum allowable moisture content of biomass feedstock in the boiler should be less than 40 w-%. The biomass such as Prosopis juliflora and chicken litter are then transported from the longer distances.

Government allows 15 % coal (total annual feedstock share) could be used during emergency situations without losing earning possibility of carbon credits. However the power plant cannot store the coal at the plant premises due to UNFCCC regulations. The plant uses South African coal (G grade) of which price is 41.4 € (3 500 Rs) per ton. The GCV of the coal is 21.8 MJ/kg and ash content 7 %. The regulations are monitored by statutory compliance.

Table 25. The key plant characteristics.

Plant characteristics	Units	Value
Installed capacity	MW_e	10
Operating capacity	MW_e	7.5
Investment cost (no land price)	mill. Euros (mill. Rs)	7.7 (650)
Boiler efficiency	%	65 – 70
Conversion efficiency (fuel-to-power)	%	21
Biomass	tons/day	450 - 500
Power Transmission	Volts	440
Carbon credit – UNFCCC	Rs/kWh	1.5 - 3.6
Employees – permanent (temporary)	persons	40(60)
Plant shut down	days/year	12
Emission savings	CO_2eq/year	46 991

Corrosion at the superheaters is not a big problem so far. Based on experiences on other similar type of plants super heaters need to be replaced every fourth year. So far this plant is operating with the original superheaters. Live steam temperature is rather low, 430 °C, to minimise the corrosion risks. Sometimes, ash clogging happens due to unburnt biomass residues in the boiler. The plant equipment are Indian made and the boiler is supplied by IJT-Johnson Thomson. The boiler uses grate firing technology. So far the plant has not faced any major accidents or shutdowns. The plant maintenance is carried out once in a month (1 day off), when the boiler is shut down for cleaning of the deposits in the superheater area. Online sootblowing of the superheaters is conducted twice per every shift. The plant emissions are not strictly regulated. The ash residuals are supplied to the farmers at free cost (Figure 48).

Figure 48. Ash removal system in the boiler (left) and aggromelated ash (right) (Karthikeyan Natarajan).

8.2 Global Power Tech Equipments Ltd. – biomass power plant in Tamil Nadu

8.2.1 Introduction

The biomass plant located at Ayalavadi village in Vandavasi city in Tiruvanamalai district in Tamil Nadu State. The biomass plant is owned by Global Power Tech Equipments Ltd. being a subsidiary of Orient Green Power Company Ltd. The capacity of the power plant is 7.5 MW_e and its operation started 2010. The total power plant investment was 330 mill. Rs in 2010 and it was estimated at the plant that currently (2014) a new same kind of power plant investment would be 440 mill. Rs. Orient Green Power Company Ltd. has 86 MWe of biomass capacity in India. It has 11 biomass plants in Tamil Nadu (4 plants), in Rajasthan (4), Maharashtra (1), Andra Pradesh (1) and Madhya Pradesh (1).

8.2.2 Biomass fuels used at the power plant

Power plant is using 30 different biomass fuels at the power plant (Table 26 and Figure 49). The main biomass fuels are bagasse, Prosopis juliflora, rice husk, coconut residues and maize stalk. The consumption of bagasse is 2500 ton/month, rice husk 3000–4000 ton/month and Prosopis juliflora 100 tons/day.

The price of bagasse is 21.9–27.9 (1 850–2 356 Rs) per ton depending on the sugar mill, the price of Prosopis juliflora 20.7–32.5 (1 750–2 750 Rs) per ton depending on the supplier, the price of rice husk 39.1 € (3300 Rs) per ton and the price of coconut residues 20.1 € (1 700 Rs) per ton. The biomass plant gate price includes the biomass price for the farmer, biomass harvesting, loading, transportation, unloading and crushing or chipping fuel processing at the plant. The gross calorific value of biomass fuels at the power plant varies from 10.5 MJ/kg up to 17.2 MJ/kg. The highest is with Prosopis juliflora and the lowest with the chicken waste. The moisture content varies at the gate from 10 to 50 w-%. At the backyard the wet biomass fuels are dried. The different biomass fuels are mixed in the feeding to the conveyor with each other. The moisture content in the combustion is 20–30 w-%.

Figure 49. Some biomass fuels used at the power plant; Prosopis juliflora (up and left), bagasse (up and right), rice husk (down and left) and chicken litter (down and right).

Table 26. Biomass price, moisture content at the gate and calorific value of some biomass fuels at the power plant.

Biomass	Price €/ton (Rs/ton)	Gross calorific value MJ/kg	Moisture content w-%
Bagasse	27.7 (2 085)	16.7	50
Casuarina leaf stem	19.0 (1 600)	15.9	20 - 25
Coconut residues	14.2 (1 200)	15.5	30 -40
Groundnut shell	41.4 (3500)	16.7	10
Juliflora	27.2 (2 300)	16.5	30 - 50
RDF	20.4 (1 727)	14.4	35 - 40
Paddy husk	39.1 (3 300)	12.6	8 - 10
Sugar cane trash	20.1 (1 700)	16.7	8 - 10
Wheat husk	26.6 (2 250)	14.3	10 - 15
Wood bark	22.3 (1 881)	14.2	40 - 45
Energy crop	11.8 (1 000)	14.6	45-50
Average	24.2 (2049)	15.3	

8.2.3 Harvesting of Prosopis juliflora for fuel

The biomass is purchased directly from the farmers. The rice husk is only purchased from the traders. The biomass is supplied by the farmers and contractors to the power plant. Prosopis juliflora is harvested around the year.

The contractor gets the permission to harvest Prosopis juliflora from the auction organised by the State Forest Department. Prosopis is growing free at the area on wasteland, beside the road, from where it is harvested. The power plant organised a visit where it was possible to see the harvest of Prosopis juliflora for the power plant. At the harvesting site Prosopis was growing on the bank of water reservoir. At the site the contractor had two teams harvesting Prosopis juliflora manually by axe. In one team there were two people (Figure 50). The productivity of one man in Prosopis harvesting is 0.75 ton/day.

Figure 50. Harvesting of Prosopis stem for fuel; manual cutting by axe (up and left), stem fuel (up and right), branches for fodder of animal(down and left) and lunch break (down and right).

8.2.4 Harvesting of sugar cane trash for fuel

The agro biomass residues are seasonal fuels at the power plant. Sugar cane trash is harvested in March and April. The sugar cane trash consists of leaf of sugarcane left on the field. The yield of sugar cane trash is 10.0–12.4 tons/ha in 12 w-% moisture content. Rice husk is harvested from March to June.

Sugar cane trash is baled on the field after sugar cane harvesting. Before baling the sugar cane trash is dried on the field. The moisture content of sugar cane bales at power plant is 8–10 w-%. The sugar cane bales are delivered by farmers or traders to the power plant (Figure 51).

Figure 51. Harvesting of sugar cane trash for power plant use; sugar cane trash on the field (up - left and right), sugar cane trash transport by tractor trailer (down and left) and sugar cane bales at the power plant (down and right).

8.2.5 Handling of biomass at the plant

The biomass is transported to the power plant with tractor trailers and lorries. Dry biomass like rice husk is stored at the covered storage area. Wet biomass is spread on the drying field in order to dry biomass using solar energy. There were altogether two drying areas in both sides of the covered storage area (Figure 52).

There were two chippers and one shredder (Figure 53). The chippers were used for Prosopis juliflora and shredders for energy grass and sugar cane trash comminution. The chipping and shredding was made under covered storage area. The productivity of one chipper was 15 tons/h and the productivity of shredder 8 tons/h. The chippers did not work very well because the grain size after chipping was high, under 300 mm.

There were in use two conveyors to transfer biomass to the boiler (Figure 54). The first one was used mainly for rice husk, bagasse and wood chips. The other one was used for sugar cane trash and energy grass chops. The feeding of biomass to the conveyor was made by excavator. The final feeding of the biomass through the grill was made manually.

Figure 52. Drying of energy grass (left) and tractor with front end loader for spreading and collecting of biomass on the drying field (right).

Figure 53. Chipping of Prosopis juliflora (left) and shredding of energy grass and sugar cane trash at power plant (right).

Figure 54. Biomass feeding conveyor (up and left) for Prosopis juliflora chips and rice husk to the boiler, biomass feeding conveyor for sugar cane trash and grass chops (up and right) at power plant, feeding (grass chops etc.) to the conveyor (down and left) and feeding grate at the at the beginning of biomass conveyor (down and right).

8.2.6 Boiler operation

The steam boiler is equipped with travelling grate. The maximum power produced is 7.5 MW. Nominal live steam temperature is 490 °C and pressure 65 bar. The coconut fronds are expected to cause corrosion problems and that’s why the share of it is limited. They have already replaced one superheater (SH II).

The plant undergoes two days maintenance operation in a month in order to clean up the boiler surfaces (removal of deposits). Additionally there is a 15 day maintenance break annually. The online soot-blower is used two times every shift (3 shifts in a day). LOI in fly ash is typically between 10-15 %. In-house electricity consumption is 10.5 %. Overall operation and maintenance costs are less than 1 Rs/kWh.

8.3 Auro Mira Energy Company – biomass power plant in Tamil Nadu

8.3.1 Introduction

The biomass plant at Kadaneri Village, T. Kallupatti Panchayat Town, Peraiyur Taluk, which is 50 km from the temple city called Madurai. The power plant is owned by Auro Mira Energy Company Private Ltd. (AME).

The size of the power plant is 10 MW_e. The power plant uses different biomass fuel. The main fuel is Prosopis juliflora whose share was about 40–50 % of the total feedstock (Figure 55). The other biomass fuels are coconut frond (15 %), plywood residues (15 %), coconut husk and coir (15 %) and agro biomass (10 %). Coconut coir is a natural fibre extracted from the husk of coconut. Agro biomass feedstock consists of bajra crop residues. It was supplied 450 tons of different biomass to power plant per day.

The price of main fuel Prosopis julflora was 24.9–33.7 € (2 100–2 850 Rs) per ton. The price of agro biomass was around 29.6 € (2500 Rs) per ton. The gross calorific value of Prosopis juliflora was 16.7 MJ/kg (4 000 kcal/kg) and moisture content at use 35 w-%.

Approximately 1.7 tons of woody biomass is needed to produce 1 MW of power. Biomass costs from the total electricity production cost were 47.3 € (4 000 Rs) per MWh.

Renewable energy certificate (REC) does not allow the power plant to sell electricity to the third party. Therefore the produced electricity is old to Tamil Nadu electricity board (TNEB).

Figure 55. Prosopis juliflora (left) and coconut husk (right) feedstock of Auro Mira power plant (Photos by Arvo Leinonen).

8.3.2 Production of Prosopis Juliflora

Prosopis juliflora is an invasive species having origin in Mexico, and South America. This fuel wood grows vigorously in dry lands of Southern Tamil Nadu and it is available for supply throughout the year. The biomass procurement team purchases Prosopis from the auctions carried out by Tamil Nadu Forest Department and Public Welfare Department. TNFD and PWD harvest Prosopis grown in ponds and government lands. The Prosopis juliflora is harvested every third year. The yield per ha in harvesting after three years is 50–75 tons/ha (dry).

Also the power plant makes contract with the local farmers to cultivate energy crops like Prosopis juliflora for the power plant in order to secure the biomass supply. The biomass procurement team provides training and personnel discussion to the farmers. At the moment power plant had two contract farmers to cultivate energy crops for the power plant. The total area of the contract farms were 100 ha in 2013.

Prosopis juliflora is harvested manually at the farm (Figure 56). First phase in harvesting is to cut delimb the stems. Harvesting Prosopis juliflora is very difficult due to the presence of thorns. After cutting the stems are combined in small heaps where they are dried. The branches of Prosopis juliflora are used local in households for cooking of feed for livestock. From the farm the Prosopis juliflora stems are transported by trucks to power plant where they are comminuted. Prosopis juliflora is harvested once in three years. The Prosopis juliflora is also used for charcoal making.

The average price of Prosopis julifilora at the plant gate was 33.1 € (2 800 Rs) per ton (Table 27). The harvesting contractor pays to the Tamil Nadu Forest Department or Public Welfare Department from the harvesting right of Prosopis 9.5 € (800 Rs) per ton being 29 % from the price of Prosopis at the gate. The harvesting costs 14.2 €/ton (1 200 Rs/ton) of Prosopis are 43 % of the gate price. The transport costs 4.7 €/ton (400 Rs/ton) are 14 % of the gate price. The rest 4.7 €/ton (400 Rs/ton) is the profit of the contractor including unloading and chipping costs (Table 27).

Figure 56. Harvesting of Prosopis juliflora at farm. Cutting (up and left), delimbing (up and right), stems (down and left) and branches (down and right) (Photos by Arvo Leinonen).

Table 27. Information of Prosopis juliflora harvesting and supply costs.

Activity	Units	Costs
Prosopis juliflora price at farm	€ (Rs)/ton	9.5 (800)
Prosopis juliflora harvesting costs	€ (Rs)/ton	14.2 (1 200)
Prosopis juliflora transport costs	€ (Rs)/ton	4.7 (400)
Prosopis juliflora harvesting and supply at power plant	€ (Rs)/ton	33.1 (2 800)
Yield of Prosopis juliflora in harvesting after three years	tons/ha	49.4 –74.1
Labors need harvesting	men/ha	125
Male labor costs	€ (Rs)/day	3.6 (300)
Female labor costs	€ (Rs)/day	3.0 (250)
Chipping costs at plant (only labor)	€ (Rs)/ton	0.53 (45)
Unloading (JCB) costs of Prosopis juliflora	€(Rs)/day	35.5 (3 000)
Prosopis juliflora harvesting area	ha	2 000

8.3.3 Biomass handling at power plant

The power plant has about 2 ha biomass storage area beside the plant from where the biomass was transferred to the boiler using conveyors (Figure 58). Half of the storage area (1 ha) had a roof made from steel plates (Figure 57). The biomass was stored but also comminuted under the storage area. If needed biomass was dried on open field beside the storage area. There were several chippers to comminute the biomass.

Figure 57. Biomass was dried on open field beside covered storage area (Photo by Arvo Leinonen).

Figure 58. The conveyor feeding biomass to the boiler (Photos by Arvo Leinonen).

8.3.4 Boiler characteristics

The steam boiler was supplied by Chinese company Wuxi Huaguang Jiang. The model is UF -46/6.47–T and equipped with travelling grate. The plant investment was about 0.7 million €/MWe (60 million Rs/MWe). The allowable maximum moisture content of the fuel is 35 w-%. If the moisture content is higher there will be more unburnt residuals decreasing boiler efficiency. The coconut coir is causing problems because of its high alkali content. The expected lifetime of superheaters coils is 2–3 years. Since 2009 superheater coils have been changed once due to corrosion (Table 28).

The plant undergoes two days maintenance operation in a month in order to clean up the boiler surfaces (removal of deposits with hammering). The deposits are also analyzed at the lab of the plant. The online soot-blower is used two times every shift (3 shifts in a day). The problems with grate clips are common here. The fuel mix ratio proved to be important for maintaining the optimal temperature and boiler environment. Around less than 10 % unburnt residuals are obtained. The fuel is directly fed into the boiler without any silos through slot chambers. Agro-biomass causes clogging/jams though the more forced DI air is passed (forking – pneumatic feeder). Superheaters are SS type/alloy which could withstand high temperatures.

The maximum power produced is 8.7 MW. The boiler height is approximately around 25 meters. Some of the important boiler parameters are listed in the table 28. The ash is dumped, but there is some R&D going on to study the possibilities for fertilizer use. Plant's own electricity consumption is about 12–13 % of the production.

Table 28. Key boiler parameters.

Parameters	Unit	Value
Total heating surface	m^2	3014
Normal capacity	t/h	46
Max design steam capacity	t/h	49.6
Max allowable working pressure	MPa	7.69
Nominal steam pressure	MPa	6.47
Nominal steam temperature	degree Celsius	495
Employees	employees/day	36

8.4 Anant Urja Ltd. -biomass plant in Madhya Pradesh

8.4.1 General information

The biomass power plant is located 15 km from the Bhopal city in Madhya Pradesh. The power plant is owned by Anant Urja Ltd. The Bhopal is the capital city of Madhya Pradesh having 1.8 million inhabitants. The size of the power plant is quite small 1.2 MWe. Madhya Pradesh Development Agency evaluates that there is still a potential of 8.4 MWe of biomass based power production in the Bhopal district. The power potential estimates are based on the 1998 biomass atlas of India report (Natarajan et al. 2014).

8.4.2 Biomass supply chain

The plant uses predominantly upgraded bamboo feedstock (stems and sawdust) that are available in abundance from nearby forests and community lands. At the plant site the bamboo clumps are comminuted. The maximum particle size is 75 mm. The bamboo yield can be even 74.1 dry tons/ha (Figure 59).

A briquetting unit is also installed at the plant site. The biomass briquettes are made from agricultural residues (soybean stalks), industrial residuals from sawmills (sawdust and shavings) and residues (bagasse) from sugar mills. The cost of biomass at the gate including transportation varies from 11.8 € (1 000 Rs) per ton to 23.7 € (2 000 Rs) per ton. The biomass briquette costs varies between 23.7 € (2 000 Rs) and 47.3 € (4 000 Rs) per ton depending on the feedstock (Figure 60). The power plant also plans to use Lantana mexicana bush from nearby forests. Lantana is an invasive weed growing naturally in shrub lands

The whole plant is located on 0.8–1.2 hectare of land. From the biomass supply chain point of view, the fuel collection and transportation is relatively efficient when comparing the availability and distribution of biomass. The collecting window for agricultural residues is seasonal and long-time storage can degrade the fuel quality. Moreover, the plant of this scale (1.2 MWe) requires smaller storage yard compared to the bigger 10 MWe power plant.

Figure 59. Bamboo stems (left) and briquette machine at power plant (right) (Photos by Karthikeyan Natarajan).

Figure 60. Different biomass fuels used at power plant. Chipped bamboo (up and left), shavings (up and right), bagasse briquettes (down and left) and soybean briquettes (down and right) (Photos by Karthikeyan Natarajan).

8.4.3 Power plant

The biomass is converted to power through gasification process. The production of biomass power involves the following processing steps: biomass processing, gasification, gas cleaning, power generation and transmission to the grid. Four distinct processes take place in the gasifier: drying of the fuel, pyrolysis, combustion and reduction. The biomass is fed to the boiler manually every 20 minutes using skip charger (bucket system). The estimated moisture content of the fuel should be less than 20 w-% (UNFCC 2006).

The plant includes a double downdraft biomass gasifier. The biomass consumption in one gasifier is 630 kg/h. Gasification takes place at a temperature range of 1 050–1 100 °C. The gasification efficiency on hot gas mode (no scrubbing) is more than 85 % and on cold gas mode (with scrubbing) is more than 75 %. The gas temperature at the gasifier outlet is between 300–500 °C. After the gas cleaning and separation, the produced gas (syngas) is then used with a 100 % Producer Gas Engines and five numbers of producer gas operated Gensets each of capacity 250 KWe aggregating a total capacity of 1.25 MW. The generator is made by Schmitt Enertec and it consumes 554 m^3/h of produced gas (UNFCC 2006).

The produced power is distributed through northern, eastern, western, north eastern Grid (NEWNE). The total plant investment cost including land ranges between 0.71–0.77 million € (60–65 million Rs) per MWe. The plant reduces emission by 6 842 tons of CO_2 annually (UNFCC 2006).

8.5 Orient Green Power Company Ltd. –biomass power plant in Madhya Pradesh

8.5.1 General information of the plant

The plant is located in Sookri village, Gadarwara block, Narshingpur district of Madhya Pradesh. The total estimated biomass based power production potential of Narshingpur district is 25.75 MWe. The capacity of the power plant owned by Orient Green Power Company is 10 MWe. The district is known for sugarcane production. There are nine sugar mills, three rice mills, two soybean mills and four thermal biomass power plants in 50 km radius. The plant construction began in 2009 and it got delayed due to issues in acquiring farmers land power transmission lines. The plant is operated periodically depending on the biomass availability.

8.5.2 Biomass supply chain

The power plant depends highly on the availability of biomass in the area. The main biomass fuel at the plant is bagasse. The power plant has established contract agreements with four neighbouring sugar mills for bagasse delivery. The collection window for bagasse is from November to April and it is directly correlated with the sugar production. Only surplus bagasse is delivered to the power plant after fulfilling the existing demand of co-generation for the sugar mills. The sugar mills are able to supply altogether 30 000–50 000 tons of bagasse annually. During the visit (January 2014) the plant was operating temporarily depending on the fuel procurement. The bagasse price at the gate was 17.8 € (1 400 Rs) per ton (50 w-% moisture). The transport distance for bagasse is 50 km.

The power plant starts operation when the target of 5 000 tons of bagasse is delivered and stored at the storage yard of the plant (Figure 61). The huge amount of bagasse storage is not recommended due to fire hazard problems (Table 29).

Power plants is using as a fuel also agricultural residues like soybean stalks, gram stalks, etc. The potential of agricultural residues is immense. The plant has established co-operation with local famers through Action for Social Advancement (ASA) to cultivate fast growing bioenergy crop called Napier grass. Currently, 6 has of agricultural land has been under Napier grass cultivation. The plant gate price paid to ASA would be 17.8 € (1 500 Rs) per ton. The farmer price is about 16.6 € (1 400 Rs) per ton. The harvesting and transport cost are 1.2 € (100 Rs) per ton.

The moisture content of wet bagasse was around 46–50 w-%. A single bagasse truck load as shown in the figure 61 would weigh 17–18 tons/truck. Typically, 22–23 truck loads are needed every day for power generation.

The general key points in biomass supply for the power plant:

- There should be several biomass feedstock and one main biomass feedstock when planning the location for the biomass power plant.
- Seasonality and short collection window of agricultural residues crops is a challenge for the biomass supply.
- Long term biomass storing deteriorates the biomass properties.
- The fuel mixture should be optimised in order to maximise the efficiency of the boiler.
- The supply chain is site specific (biomass fuels and size of the plant)

Figure 61. Bagasse lorry load (up and right), biomass storage yard (up and left), unloading of bagasse bales from lorry at storage yard (down and left) and bagasse bales piles (down and right).

Table 29. Information of the bagasse based power generation at the plant.

Parameters	Unit	Value
Bagasse requirement	ton/day	380
Bagasse price	€ (Rs)/ton	16.6 (1 400)
Bagasse MC	w-%	50
Bagasse GCA	kcal/kg	2 400
Yard storage	tons	5 000
Truck capacity	tons/truck	17-18
Availability	months	Nov-April
Procurement distance	km	<50

8.5.3 Purchase agreement

ASA is a non-profit organization aiming to improve the livelihood of rural people. ASA is operating at the moment in more than 1 000 villages in Madhya Pradesh. ASA has strong relationship with the local farmers through their various activities. The biomass purchase agreement has been made between ASA and power plant. Based on the agreement ASA will procure biomass directly from the farmers and then sells the biomass to the power plant. In this case, the power plant is not operating with farmers. The biomass is paid to the farmers in 15 days. The biomass procurement strategy of the power plant is shown in the figure 62.

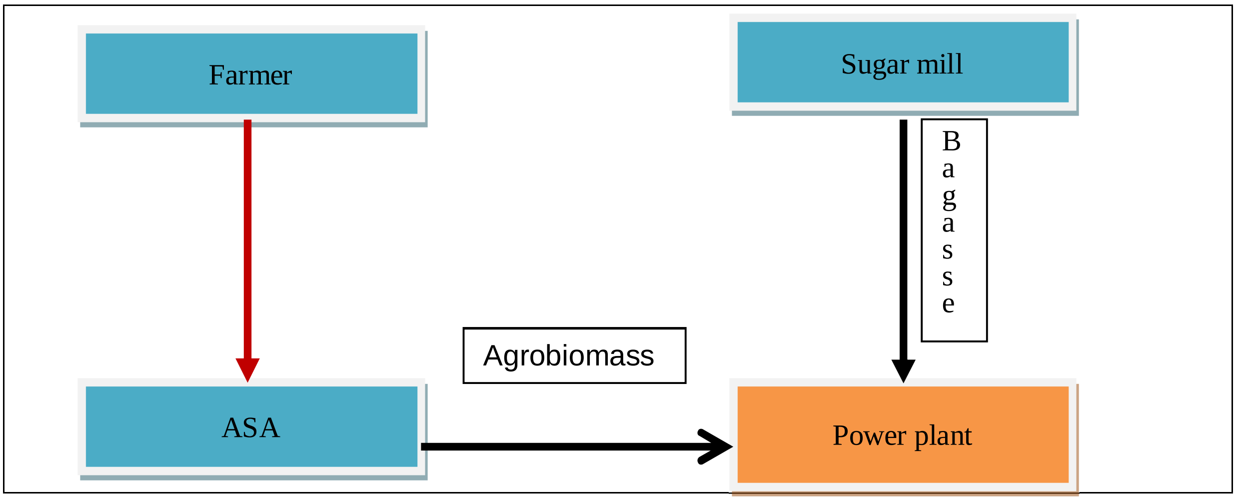

Figure 62. Biomass procurement strategy of the power plant.

8.5.4 Power plant

The plant is operated periodically depending on the biomass availability and financial circumstances to buy biomass. Although the constant supply of biomass forms an important issue.

The key plant characteristics are given in the table 30. The plant uses Rankine cycle technology to generate power from biomass. The biomass is fed in to the travelling grate boiler through biomass conveyer. The boiler capacity is 52 tons of steam per hour. The steam pressure in eth boiler is 66 kg/cm^2 and temperature 465 °C. The generated steam is passed through the 10 MWe steam turbine generator to produce electricity. The electrostatic precipitator (ESP) removes the particulates from the flue gas before excreted out through chimney.

The ash content of biomass is about 10 %. The plant own electricity consumption is 10–13 %. The generated power is sold to the state government at a fixed tariff.

*Table 30. The key power plant characteristics***.**

Plant characteristics	Units	Value
Installed capacity	MWe	10
Investment cost (with land price)	mill € (mill Rs))	9.5 (800)
Boiler efficiency	%	65-70
Conversion efficiency (fuel-to-power)	%	21
Biomass	tons/day	380
Grid voltage (power evacuation)	kV	33
Carbon credits – UNFCCC	€ (Rs)/MWh	17.8-42.6 € (500-3 600)
Employees – permanent (temporary)	persons	40 (60)
Emission savings	CO_2 ton/year	52 980

8.6 Shendra Green Energy Ltd. –biomass power plant in Maharahstra

8.6.1 General information

The biomass plant is owned by Shendra Green Energy Ltd. and located at Shendra Maharashtra Industrial Development Corporation (MIDC) –industrial district. The power plant is 16 km from the Aurangabad city. The Aurangabad is the fifth largest industrial district in Maharashtra after Pune, Raigad, Nashik and Thane.

The district has five similar MIDCs. Shendra MIDC covers an approximately 1 000 ha industrial park infrastructure provided by the state government to promote the industrial growth and development in that region. Several automobiles industries (like Audi India, Volkswagen, Skoda Auto, etc.), beverages, pharmaceutical and other companies are located in Shendra MIDC.

The capacity of the power plant is 13 MWe. The plant operates only six months in a year from November to April. The power generated in the plant is being sold to Maharashtra State Electricity Distribution Company Ltd. (MSEDCL) through Maharashtra State Electricity Transmission Company Ltd. (MSETCL).

8.6.2 Biomass used at the power plant

The plant use mainly cotton stalks and soybean husks as a primary fuel. It uses also other biomass fuels like Prosopis and maize cobs as secondary fuels (Figure 63). The biomass price and fuel characteristics are given in the table 31. The uncertainty of biomass supply is a big challenge for this slightly bigger size biomass plant. The cotton crop is mainly rain-fed and the farmers cultivate cotton depending on the rainfall.

There is abundance biomass available for the power plant. The total surplus was 2.5 times more than the annual power plant requirement (110 000 tons). The poor logistic network for collection and delivery is a major problem to the continuous power plant operation. Previously in practice the agricultural residues were used as a fuel in households and part of the residues were burnt on the field. Power plant has as a long term strategy to secure their biomass supply. The power plant has started negotiating with state governments to acquire wastelands for raising energy plantations.

Figure 63. Different biomass fuels used at the power plant. Cotton stalks (left), maize cobs (middle) and soybean husk (right).

Table 31. Fuel properties of different biomass used at the power plant.

Parameters	Units	Cotton stalks	Maize cobs	Soybean husks
Biomass price	€(Rs)/ton	24.9 (2 100)	28.4 (2 400)	35.5 (3 000)
Moisture content	w-%	53	20	25
Net calorific value	GJ/ton	16.7	17.5	16.5

8.6.3 Biomass fuel supply chain

The maximum transport and collecting distance of biomass to the power plant is 120 km. The biomass is procured mainly from Aurangabad and Jalna districts. The Punjab Renewable Energy Systems Ltd. (PRESL) is responsible for collecting and transporting the biomass from the farmers to the power plant. The mobile drum chippers are used to chip the fuel at the field and chipped biomass is transported to the power plant. The biomass is collected from the farmers and stored in storage centres and later delivered to the power plant. Also, the farmers/agents can transport biomass directly to the power plant. Approximately, the power plant consumes 350–380 tons of biomass every day. There is no definite vehicle transportation system since every individual or firm uses whatever possible vehicle options to transport the biomass from the field to the power plant (Figure 64). The vehicles are covered to avoid the leakage of loose chipped agricultural residues.

The cost break down for soybean supply costs to the power plant by a TATA pickup car is given in the table 32. The agents generally pay read cash to the farmers at the field and then claim back from the power plant with 15 days of crediting period.

Table 32. Cost break down for a soybean transported small TATA pickup car.

Parameters	Units	Costs
Truck payload	tons	1.2
Farmer price	€(Rs)/ton	11.8 (1 000)
Chipping costs	€(Rs)/ton	3.6 (300)
Transport costs	€(Rs)/ton	8.3 (700)
Profit/earnings	€(Rs)/ton	11.8 (1 000)
Total price	Rs/ton	**35.5 (3 000)**

Figure 64. The different kind of vehicles used for biomass transportation.

8.6.4 Power plant

The power plant was commissioned in 2008. The power plant uses in steam-power Rankine cycle. The production capacity of steam in the boiler is 60 tons per hour. The electricity production capacity is 13 MWe fed into the MSEDCL grid through 132 kV line.

The plant boiler was designed according to the biomass fuel characteristics and particularly cotton stalk as the primary feedstock. In the conventional travelling grate boiler it can be used different kind biomass fuels. The plant has installed comparatively with a low pressure and low temperature (45 kg/cm^2 and 440 °C) when compared to similar grate fired boilers in Tamil Nadu and Madhya Pradesh.

The major technological barriers for using cotton stalk are listed below:

- High temperature and pressure boiler designs are unsuitable to combust cotton stalks as it contains high chlorine and potassium.
- High alkali content in cotton stalks creates coating on the superheated coils which in turn reduces the heat transfer co-efficient, if 100 % cotton stalks are used. Frequent shut downs are then needed to clean the superheated coils although soot-blowers are used for steam cleaning the superheater. Increasing the boiler furnace size was the only option to overcome this constraint, if plant is forced to use 100 % cotton stalks due to biomass availability or difficult conditions.
- The cotton stalks are fibrous in nature and therefore, fuel feeding system has to be modified from the screw feeder or drag chain feeder option. The plant has installed over bed firing feeder with rotating drum feeding.

8.7 Yash Agro Energy Ltd. biomass –biomass power plant in Maharashtra

The biomass power plant of Yash Agro Energy Ltd. is commissioned in 2008. It is located in Kolari village of Chandrapur district of Maharashtraand. The total power plant land area is 2.6 ha. The power plant operates using rice husk as main fuel and sawdust as a subsidiary fuel. Power plant has a capacity of 8 MWe. The electricity generation capacity of the plant is about 63.4 million kWh per year. During the financial year 2009–2010 the total generation was 60.9 million kWh. The main share of the electricity was sold by state grid to Reliance Energy Trading Ltd. The income was 6.67 Rs/kWh (Meshram 2010).

About 195 tons of rice husk is required per day to generate electricity in the plant. The power plant uses also sawmill residues and wood chips as a fuel. The rice husk price varies from 26.6 € (2 250 Rs) to 28.9 € (2 450 Rs) per ton depending on the type, moisture content and season. Generally around 10–12 traders are in the operation for supply of rice husk through the year. There are also other companies like brick factories that are competing from the same biomass. Moreover the moisture content increases during the monsoon season due to lack of proper and covered storages at the rice mills. There are also problems to export the generated power because of grid disturbances (Meshram 2010).

The plant employs 107 people continuously for plant operation and maintenance. They also employ about 100 people in their rice husk logistics and collection. Further about 100 people in the villages find jobs in loading/unloading rice husk. The total direct employment impact in the area is 307 permanent jobs (Meshram 2010).

8.8 Punjab Biomass Power Ltd. - biomass power plant in Punjab

8.8.1 Introduction

Biomass power plant in Ghnaur town Punjab is owned by Punjab Biomass Power Ltd. (PBPL). The Punjab Renewable Energy Systems Ltd. (PRESL) is responsible for the biomass supply and energy plantation in Punjab power plant. PBPL and PRESL are subsidiaries companies of Bermaco Energy Ltd. The biomass plant has been in operation since 2010 (Bermaco 2014) (Figure 659).

The capacity of the plant is 12 MWe. Biomass plant is using about 700 tons of biomass per day and 120 000 tons of biomass per year (Energy future 2013). The plant produces power mainly from paddy straw and not from paddy husk, which is already used widely as an expensive commercial fuel. The power plant is also using other biomass fuels like cottons stalk, maize cob, sugarcane trash, bagasse, mustard stalk and soybean husk (Bermaco 2014).

Figure 65. A straw fired power plant in Punjab (Vidlund 2013).

8.8.2 Biomass production and supply technology

The fuel management in Punjab power plant is carried out by the Punjab Renewable Power Ltd. (PRPL). PRPL is owned by Bermaco (Bermaco 2014).

The average farmer in Punjab works on a farm that is roughly two hectares in area. This two-hectare plot produces around 8 tons of paddy straw every year. When sold to a local power company this otherwise useless waste can become a source of extra income for the farmer (Energy future 2013).

Rice is grown in the kharif season which is synonymous to summer or wet season and it extends from May to October. The collecting window of straw is only 6–8 weeks. During this time 2000 people are employed for harvesting by the company (Energy future 2013).

Paddy in India is harvested manually using sickle or using combines. The manual harvesting results in cutting very close to the ground and hence all the straw is recovered from the field. But harvesting by combines usually leaves about 30 cm of standing straw in the field. 70 to 80 per cent of the crop is harvested by combines in Tamil Nadu (Bioenergy India 2011).

After paddy harvesting the first working in paddy straw harvesting and supply system is the cutting the straw on the field near the ground using cutters (Figure 66). The next working phase is baling using rectangular baler operated and pulled by the farm tractor. The balers are made in Germany or in Japan. The density of the straw bales is 150 kg/m^3. The cutting and baling working phases are made by contractors. They are using the machines owned by the company (Vidlund 2013).

After baling the bales are loaded in tractor trailers by which the bales are transported to the local collecting points. The average transport distance from the farm to collecting centre is about 5–10 km. There are all together 8–10 collecting centres. The land area of each collecting centre is 4–6 ha. The collecting centre has a fence, weighing bridge and also electricity. The total land area of the collecting pints is 52 ha. The bale storages are not covered in the collecting centres. The energy loss of straw in the storage phase is 15–20 %. The company has considered to cover the bale storages (Vidlund 2013).

The straw bales are transported to power plant by tractor trailers which can carry 4–5 tons of straw each. At power plant there is a storage which is partly covered. The volume of covered area where the straw bales are chopped is 700 tons. The open storage area is bigger than the covered area (Vidlund 2013). The maximum paddy straw transport distance from the collecting centres is about 30 km (Bermaco Energy Ltd. 2014).

The straw bales are chopped at power plant at the covered storage area (Bermaco 2014) (Figure 67). It has been noticed that there is a risk for fire in the fuel storages if the moisture content has increased because of the rain. There have been several fires in the fuel storages. The fires in fuel storages are one of the biggest risks in using straw as fuel (Vidlund 2013).

Figure 66. Cutter (up and left), baling with tractor baler (up and right), bales road transport to the collection centre (below and left) and bale storage at collecting centre (down and right).The photos are not from Punjab.

Figure 67. Loading of straw bales to the conveyor transferring material to the crusher at the Universal Power plant in Channu Village (Dailypost 2014).

8.8.3 Fuel price and quality

The price of straw at the plant is about 2 500 Rs/ton. The price of domestic coal is 5000 Rs/ton. The heating value of the coal and straw is the same. The farmers are paid for the harvesting and for the material. The price is the same for all farmers and it is announced at the beginning of the harvesting season (Vidlund 2013).

The ash, alkali (K) and chloride content of paddy straw is high. Combining rice straw with other fuels can be positive for the chemical composition of the fuel. The calorific value of the fuel is 3 200 kcal/kg with an average moisture content of 15 w-% (Vidlund 2013).

8.9 Transtech Green Power Ltd. -biomass power plant in Sanchore in Rajasthan

8.9.1 Introduction

Transtech Green Power Ltd. has set up a 12 MWe biomass power plant in Sanchore in Rajasthan state (Figure 68). The commercial electricity production has started in 2010. The total costs for the power plant were 67 000 000 Rs. The planned electricity production is 86.4 million kWh per year (Tandon 2010).

8.9.2 Biomass fuels at the power plant

The primary biomass of the plant is Prosopis juliflora. The biomass use in the power plant is about 100 000 tons per year. The assessment is based on the gross calorific value (GCV) of 16.5 MJ/kg (4.6 kWh/kg) of Prosopis juliflora in about 25 w-% moisture content.

Prosopis juliflora is a very hardy plant and requires very less water to grow. It can grow very fast and is ready for harvest in 2 to 3 years. A grown up plant once harvested grows back to its original size in the next 16 to 18 months. The yield of Prosopis juliflora is 15–20 tons per hectare every year. Hence a safe harvest cycle of every two years can be followed with the existing Prosopis juliflora plantation (Transtech green power Pvt. Ltd. 2014). The harvesting area of Prosopis juliflora for the power plant is 5000–6 500 ha and cultivation area two times more 10 000–13 000 ha (Tandon 2010).

There is a lot of Prosopis juliflora biomass available around the plant because of the extensive plantations done a long time ago to stop desertification. At the moment there are Prosopis juliflora plantations on government, private land and alongside the roads (Transtech green power Ltd).

The company has an objective to establish commercial Prosopis juliflora plantations together with the local farmers. The company’s agriculture team is encouraging, educating and assisting farmers to invest for Prosopis juliflora plantations in 50 km radius from the plant. The commercial plantations are different from the exiting plantations which are planted without any commercial intention. It is planned to plant almost 5 000 ha of Prosopis juliflora on commercial land (Transtech green power Pvt. Ltd.). It is about 50 % of the total Prosopis juliflora harvesting area needed to deliver enough biomass for the plant.

Biomass plant has the most positive effect to the rural development and creation of additional employment in the rural sector (Transtech green power Ltd.).

Figure 68. Transtech Green Power Ltd. has set up a 12 MWe biomass power plant in Sanchore in Rajasthan state (Tandon 2014).

8.9.3 Prosopis juliflora procurement and supply

Prosopis juliflora is harvested manually by the farmers (Figure 50) like in Orient green power plant in Tamil Nadu. The harvested Prosopis juliflora stems are first transported to the fuel collection centres like in straw fired power plant in Punjab (Figure 69). Collection centres are located around the power plant. In the collection centres biomass is stored in the stockpiles only about 4–5 days. The distance of the collection centres from the power plant is 25–33 km (Tandon 2010).

From the collection centres the Prosopis juliflora is transported by tractor trailers to the power plant (figure 70). The storage area for the Prosopis juliflora is located at the power plant. The target is to store biomass for five to six months at the power plant.

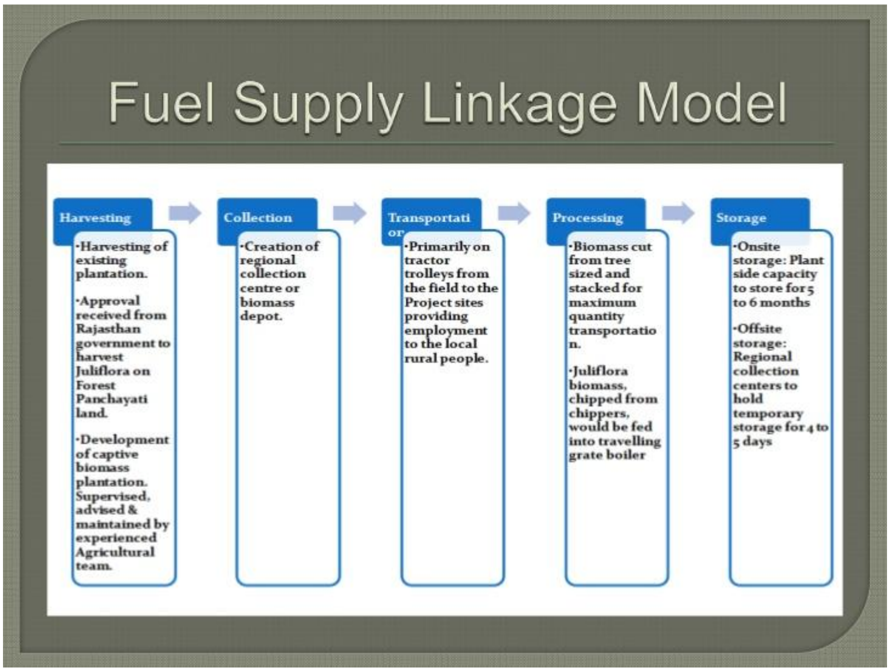

Figure 69. Fuel supply system used in power plant in Sanchore (Transtech green power Ltd.).

Figure 70. Prosopis juliflora delivery to the power plant with tractor trailers in Rajasthan (Transtech green power Ltd.).

8.10 Benefits for the rural development

A biomass power plant operation has the most positive effect on the rural development and creation of additional employment in the rural sector. The 12 MW biomass plant would infuse approximately 160–170 mill. Rs annually into the rural economy in fuel supply. It is estimated that the fuel supply would give work for 500 people in the rural area (Bioenergy 2010).

9. Conclusions and summary

Energy use in India

- Commercial primary energy production in the country for 2009/2010 was around 457.2 Mtoe. Coal, oil and natural gas oil accounted for 97.0 % of the total primary commercial energy production.
- The total renewable energy (hydro, solar, waste, bagasse and agro biomass) installed electricity capacity was 26 368 MW at the end of 2012 being about 11.1 % of the total electricity production capacity.
- The share of renewable energy accounts for only 2.5 % of the total commercial primary energy supply.
- The installed biomass electricity capacity was 2665 in 2011. It is only about 1.3 % of the total installed electricity capacity (210 952 MW) in India in 2012.
- Biomass is an important energy source for India when taking into account also the uncommercial energy production. About 32 % of the total primary energy consumption is still derived from biomass and more than 70 % of the country's population depends on it for its energy need.

Biomass fuels

- There are many different kind of agricultural residues available for energy in India. One power plant can use 30 different biomass fuels. The main agro biomass fuels are paddy straw, cotton stalks, paddy husk, wheat pod, cotton husk and maize stalks. The availability of agricultural residues depends on the state.
- The main energy crop species in India are Bamboo, Casuarina and Prosopis juliflora. The most suitable energy crops for India is Prosopis juliflora. Prosopis juliflora is a fast growing tree and it already grows wild on extensive areas of wasteland. Casuarina equistifolia is also a fast growing tree that can be cultivated on marginal wasteland and be harvested on a rotating basis from the third to fourth year like Prosopis juliflora. Bamboo is mainly used for pulp and paper making. The yield of Casuarina can be in plantations 40 tons and yield of Prosopis 10 tons per ha per year.

Biomass fuel properties

- Normally biomass moisture content in combustion is low, 20–30 %. This moisture content can be achieved by solar drying in Indian hot conditions.

- Gross calorific value of biomass fuels is quite good, 15.1–19.0 MJ/kg. Paddy husk has the low calorific value (15.6 MJ/kg) because of high ash content. Prosopis juliflora (17.7 MJ/kg) and bagasse (19.0 MJ/kg) have the high gross calorific values.
- The alkali and chlorine contents are high in agricultural fuels causing many ash related problems for combustion (e.g. slagging and corrosion).

Biomass potential

- The agro biomass residue potential for energy in India is about 18 000 MWe. The biomass potential of wasteland is 6 200 MWe. This can be much more higher when energy crops are started to cultivate on wasteland in large amounts.
- At the moment the installed power capacity in 130 biomass power plants was 990 MWe in 2011.

Biomass price

- The biomass fuel price has been increased by 30–40 % per year during the few years. At the end of 2013 the price of biomass at the power plant gate was 11.8–35.5 € (1 000–3 000 Rs) per ton depending on the biomass fuel and the state. The price includes farmer price, procurement, transport and sometimes chipping.
- One of the cheapest biomass fuel in Tamil Nadu is coconut frond 14.2 € (1 200 Rs/ton) and one the most expensive fuel is Prosopis juliflora 27.2 €/ton (2 300 Rs/ton). The reason for the high price of Prosopis juliflora is that one must harvest it before delivery to the power plant.
- The biggest share of the biomass fuel price at the gate goes to the farmer. The farmer’s share was in Rajasthan 80 % from the gate price in 2011. The share of trader’s real profit was only 8.3 % in Rajasthan . The rest of the biomass price (11.7 %) at the gate consists of transport, storing and handling costs.
- The price of briquettes (29.9–42.2 €/ton, 2 530–3 565 Rs/ton) is 55–80 % higher than the price of raw material (16.6–27.2 €/ton, 1 400–2300 Rs/ton). The as received calorific value of briquettes is higher than the biomass fuels. That is why the price per MWh is not so much higher than per ton.
- The price of biomass around the power plant is increased soon after the power plant has been commissioned.

Biomass supply

- The logistics of transporting, handling and storing the bulky and variable biomass material for delivery to the bioenergy processing plant is a key part of the supply chain that is often overlooked by project developers.
- The major problems in use of crop residues for energy source relate to their thin spread over large area after crop harvest and low bulk density. The low bulk density creates problems in handling, transport and storage.
- Biomass procurement and supply to the power plant is organised by farmers or biomass suppliers (traders) or contractors. At the moment more and more the power companies are using contractors in biomass procurement and supply.
- There are only 2–3 weeks after crop harvesting to collect biomass residues from field before the next crop sowing on the field.
- The transport vehicles are small ones (2–12 tons) because of the bad road conditions in India.
- Many of the working phases in the biomass supply (procurement, loading and unloading, feeding to the chipper) chain is made manually.
- In small power plants (2–10 MWe) biomass is delivered directly from the farm to the power plant. In bigger power plants (> 10 MWe) collecting centres are used as storage areas from where the biomass is supplied to power plant.
- The maximum transport distance from the farm is about 50 km. The transport distance from the collecting centre to the power plant is 25–30 km. In some cases in Tamil Nadu the transport distance for plywood residues to the power plant from Kerala is more than 100 km.

Incentives for biomass use for energy

- There are different incentives for biomass power plants in India.
- The main important incentive for power plant is the government's biomass tariff for electricity. It is updated annually. In 2012 the biomass electricity tariff is 4.2–5.4 Rs/kWh depending on the state. That is not enough because the electricity production costs are about 6.1 Rs/kWh.
- The biomass power plants can use 25 % coal annually without losing the right for tariff price.

- Clean Development Mechanism (CDM) and Renewable Energy Certificate (CER) benefits are also available to boost biomass electricity production. These benefits are similar. CDM is an international but CER is national mechanism. The value of Renewable Energy Certificate (REC) for bioenergy in Tami Nadu is about 17.8 €/MWh (1 500 Rs/MWh).
- Also in India there is available investment subsidy for the power plant investment coming from the Indian government. It is small, about 2 %.
- The share of biomass fuels costs are about 41 % of the electricity production costs.

Biomass power plants

- Power plants are using different biomasses in order to secure the biomass fuel supply.
- There are some hectares storage and handling area for the biomass at power plants. On these storage areas power plants are drying biomass and having them as a buffer storage.
- Many of the biomass power plants (72) from 118 have been closed in India in 2012 because of the high biomass fuel price and because the Government has not updated the tariff price for electricity annually.

Power plant technology

- Power plants are made in India or in China. The typical sizes of biomass power plants are 7.5–15 MWe. The biomass fuels are local fuels and energy content of them is low. If the transport distance is too long (more than 50 km) the transport costs become too high.
- Power plants have grate firing technology in the boiler. The steam values are not so high.
- The electrical efficiency of the plants is low, 20–22 %.
- Also the maintenance requirements of the power plant are high. The main reason is the high alkali metal and chlorine contents of the agro biomass fuels which cause deposit formation on boiler surfaces.
- The handling and feeding of the biomass to the conveyor transferring biomass to the boiler is made by machines but also a lot of man work is used in these operations.

Socio-economic impacts of biomass use for energy

- Biomass use has positive impacts in country side because it gives job opportunities for the farmers. There can be 300 farmers procuring and delivering biomass to 10 MWe power plant.

- The 10 MWe power plant gives full time jobs for about 100 people in operation and fuel handling at the power plant.
- All together 10 MWe power plant's employment effect is calculated to be about 300 man years.
- Combustion ash is used as a fertilizer on farm. The farmers can take free of charge the ash from the power plant for their own use.

Literature

Agneya carbon ventures. 2011. Renewable projects in India: what to adopt-CDM or REC. In: https://agneyablog.wordpress.com/2011/02/14/renewable-projects-in-india-what-to-adopt-cdm-or-rec/. Cited 2014.

Alakangas, E. 2000. Suomessa käytettävien polttoaineiden ominaisuuksia (Properties of fuels in Finland). VTT Tiedotteita – Research Notes 2045. In Finnish. 172 p. + app. 17 p.

Autoconsumo energetico. 2014. The Indian biomass sector (part 1) – The story thus far. In: http://www.energias-renovables.com/articulo/the-indian-biomass-sector-part-1. Cited 2014.

Bamboo house India. 2014. Bamboo resource position in India. In: http://www.slideshare.net/greenlivelihoods/bamboo-resouce-in-india. Cited 2014.

Bermaco Energy ltd. 2014. Power generation from biomass. In: http://wretc.in/presentation/day2/link41.pdf. 18 p. Cited 2014.

Bioenergy India. 2011. Biomass power generation potential, incentive and tariff – snap shot. Ministry of New and Renewable Energy, Government of India. Bioenergy India, 9-11/2011. Pp. 32-35.

Bioenergy consult. 2013. Biomass sector in India – Problems and Challenges. In: http://www.bioenergyconsult.com/biomass-india/. Cited 2014.

Central Arid Zone Research Institute (CAZRI). 2014. Ecology of Prosopis juliflora in the arid regions of India. In: http://www.fao.org/docrop/006/ad321e/ad321e04.htm. Cited 2014.

Combustion Gasification & Propulsion Laboratory (CGPL). 2014. Biomass resource atlas of India. Source: http://lab.cgpl.iisc.ernet.in/atlas/Tables/Tables.aspx/. Cited 2014.

Dalkia Energy Services Ltd. 2011. Biomass fuel supply study in the state of Rajasthan. 41 p.

Department of public relation of Madhya Pradesh. 2013. In: http://www.mpinfo.org/MPinfoStatic/english/articles/2013/110813Lekh24.asp. Cited 2014.

Dubey, A. & Chandra, P. 2014. Energy from cotton stalk and other agro residues. In: https://www.icac.org/projects/CommonFund/20_ucbvp/papers/01_dubey.pdf.

Dubey, A., Chandra, P., Padhee, D. and Gangil, S. 2010. Energy from cotton stalks and other residues. In: https://www.icac.org/projects/CommonFund/20_ucbvp/papers/15_chandra.pdf.

EAI catalyzing cleantech in India. 2014. Biomass power potential in India – electricity generation potential in MW.
In: http://www.eai.in/ref/ae/bio/pot/biomass_power_potential.html. Cited 2014.

Green clean guide. 2012. Biomass cogeneration scenario in Maharashtra and benefits of renewable energy certificates. In: http://greencleanguide.com/2012/06/26/biomass-cogeneration-scenario-state-maharashtra-benefits-renewable-energy-certificates/

IEA. 2008. Combined Heat and Power: Evaluating the benefits of greater global investment, OECD Publishing, Paris.

IEA. 2013. Energy Balances of Non-OECD Countries (2013 Edition), OECD Publishing, Paris.

IEA. 2014. CHP/DC Country Scorecard: India, The IEA CHP and DHC Collaborative.

Indian energy index. 2014. Renewable energy certificates.
In: http://www.iexindia.com/products/rec/overview.aspx.

Indian power sector. 2014. Overview of Indian power sector. In: http.indianpowersector.com.

Keralaagriculture. 2014. Bamboo for integrated rural development.
In: http://www.keralaagriculture.gov.in/htmle/bankableagriprojects/fw%5CBamboo.htm.

Käyrä, P. 2014. Biomass resource assessment in Madhya Pradesh, Maharashtra and Tamil Nadu. Sustainable Bioenergy Solutions for Tomorrow (BEST). WP 2 Task 2.3 report.

Madhya Pradesh Urja Vikas Nigam Ltd. (MPREDA). 2014. Mr. Avaneesh Shukla. Personal communication/field visit data collection.

Maharashtra Energy Development Agency (MEDA). 2014. Power generation from Renewables. MEDA’s New Frontier. Cited 2014.

Meshram, J. 2010. Review of MNRE supported biomass projects in Maharashtra. Ministry of New and Renewable Energy, Government of India. Bioenergy, June 2010. Pp. 33.

Mehra, S. & Mehra, L. 2007. Bamboo cultivation – potential and prospects. Technical Digest, issue 10, 2007.

Ministry of new and renewable energy of India (MNRE). 2014. Biomass power/Cogen. In: http://www.mnre.gov.in/schemes/grid-connected/biomass-powercogen/. Cited 2014.

Mohita, N. 2014. Notes on Agricultural Seasons and Major Crops in India In: http://www.yourarticlelibrary.com/notes/notes-on-agricultural-seasons-and-major-crops-in-india/12791/.

MSS research 2001. Innovation strategies for employment generation and rural prosperity in agriculture in Tamil Nadu. In: http:// www.mssresearch.org./innovation_strategies_for _wasteland-development.

Natarajan, K., Pelkonen, P., Leinonen, A. and Kärki, J. 2014. Field visit to Madhya Pradesh and Maharashtra.

Paliwal, A. 2012. A looming biomess: In http://www.downtoearth.org.in/content//looming-biomess.

Pelkonen, P., Natarajan, K., Pradipta, H., Leinonen, A. and Kärki, J. 2014. Field visit to Tamil Nadu 21- 27 November 2013.

Palanna, P. 2014. Eucalyptus in India.
In: htpp://www.fao.org/docrep/005/ac772e/ac772e06.htm. Cited 2014.

Patel, B. and Gami, B. 2012. Biomass characterization and its use as solid fuel for combustion. Insica journal of energy & environment 3 (2): 123-128, 2012.

Pothan, R. 2012. The Indian biomass sector (part 1) – the story thus far.
In: http://www.energias-renovables.com/articulo/the-indian-biomass-sector-part-1.

Renew India campaign. 2014. Renewable energy installed capacity in India reaches 26 368.36 MW. In: http://www.renewindians.com/2012/12/Renewable-Energy-Installed-Capacity-in-India.html. Cited 2014.

Press Information Bureau, Government of India 2012. Electricity through cogeneration: A promising development, http://pib.nic.in/newsite/efeatures.aspx?relid=80020.

Press Information Bureau, Government of India 2013. Electricity from sugar mills, http://pib.nic.in/newsite/PrintRelease.aspx?relid=98949.

EnergyNext. 2014. MNRE to continue incentives for biomass power projects. In: http://www.energynext.in/mnre-continue-incesntives-biomass-power-projects/.

Sankar, V. Tips to increase yield in Casuarina junghuhniana plantation. Source: http://agrowmania.blogspot.fi/2010/05/tips-to-increase-yield-in-casuarina.html.

Singh, M., Singh, B. & Mahla, S. 2013. Combined Heat and Power Scenario in Commercial Sector, International Journal on Emerging Technologies, Vol. 4, No. 1, pp. 81-87.

Sonde, R. 2011. Biomass resource for power generation in India. Bioenergy India. Issue 9-10, 2011.

Sustainabilitynext. 2013. India's green gold ?. In: http//sustainabilitynext/.in/cover-story/Indians-green-gold/.

Stille, L. 2011. Economic feasibility and socioeconomic impacts of four bio-salinen agro-forestry systems in Haryana, India. Bioenergy June 2011.

TERI. 2014. Indian energy sector: An overview. TERI energy data directory and yearbook. 2012/2013.14 p.

Tamil Nadu Energy Development Agency (TEDA). 2014a. Renewable Energy Installations. http://teda.in/. Cited 2014.

Tamil Nadu Energy Development Agency (TEDA). 2014b. Power sector at a glance 2011.

Tandon, A. 2010. Industry experience using Prosopis juliflora. Ministry of New and Renewable Energy, Government of India. Bioenergy, June 2010. Pp. 15 – 18.

Transtech green power Pvt. Ltd. 2014. Juliflora as fuel for green power. In: http://www.slideshare.net/AnuragNEEV/juli-flora-as-biomass-for-green-energy.

Umamaheswaran, K. and Vatra, V. 2007. Physico-chemical characterisation of Indian biomass ashes. Fuel 87 (2008) 628 – 638.

United Nations 2014. Clean Development Mechanism (CDM). In: http://unfcc.int/kyoto_protocol/mechanisms/clean:devlopment_mechanism/items/. Cited 2014.

UNFCC. 2006. Clean development mechanism. Project design document form.

Vidlund, A. 2013. Travel report to Punjab biomass Energy Ltd. 12 MW biopower plant in Punjab. 3p.

Appendix 1

Table 1. The production and surplus of the main crop residues in key Indian states.

Crop residues	Major sates having surplus of crop residues	Production of crop residues million ton/a	Surplus of crop residues million ton/a
Rice	Punjab, Haryana	18.6	15.0
Wheat	Punjab, Haryana, Uttar Pradesh, Rajasthan. Madhya Pradesh	67.6	15.4
Sugarcane	Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andra Pradesh, Gujarat	26.9	21.6
Groundnut	Gujarat, Tamil Nadu, Karnataka, Andra Pradesh	15.4	3.3
Mustard	Rajasthan, Uttar Pradesh, Madhya Pradesh, Haryana, Gujarat	9.4	4.5
Cotton	Gujarat, Maharashtra, Haryana, Punjab, Rajasthan, Karnataka	29.4	11.8
	Together		**71.6**